

IBA

TECHNICAL REVIEW

4

Television Transmitting Stations

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INDEPENDENT
BROADCASTING
AUTHORITY

4 Television Transmitting Stations

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Introduction

Sometimes in television broadcast engineering there is a danger of losing sight of fundamentals – no matter how good programme origination may be, in the outcome the technical quality of the service stands or falls by its success in reaching the viewer. At some time in the future this vital link may depend on the techniques of space communication or the electronic grid. But at present it is the terrestrial transmitter network that is important, all-important.

In the sixties the decision was taken in the UK to change line-standards, a traumatic undertaking that required the establishment of a duplicate transmitter network for which frequency space could be found only by going to the largely undeveloped UHF bands. Until then these had been used in the United States to provide additional local support to the main VHF bands; elsewhere hardly at all. Could effective national coverage be achieved on UHF-only networks? It would take many more transmitters and much higher effective radiated powers than were needed on VHF. But how many shadows and gaps? How much variation of signal strengths within the same localities? How reliable and stable would be UHF receivers?

Today we have almost – but not quite – bridged the gap between VHF and UHF coverage – with the difference that the planning standards adopted for UHF are far more stringent. We can now foresee the problems of the last few per cent. But we can also take pride in what has been achieved in the UK both by the BBC and the IBA.

This volume of the *Technical Review* explains what we in the IBA have done in building our transmitting stations – but more importantly what we are doing now. How transmitting stations have evolved and been refined and their cost-effectiveness improved. The saving in costs could easily be lost sight of behind the high cost of providing service to the final small gaps: but it has been very real and very important.

The evolution of the IBA network of transmitting stations is unique. Its rate of growth, particularly in UHF, and the engineering constraints have resulted in the need to overcome many design problems. It has also emphasized the benefits of a high degree of standardization – to an extent seldom possible in broadcasting organisations that have evolved more slowly over a longer period.

This applies not only to the electronics for a network of unattended stations but also to such questions as building designs and control systems – and to the administration and monitoring of many concurrent projects.

Considerable attention has been paid to what for some engineers might be the most significant constraint of all: the need to provide transmitting stations that are technically good but within the economic realities of an advertisement-financed television broadcasting system which receives no public funds.

This volume then is an account in miniature of the work of the IBA's Station Design and Construction Department, from whence all the contributions have come.

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Evolution of a Transmitter Network

Synopsis

The evolution of the IBA television transmitting stations has resulted in a network which can justifiably be called unique. This is in part because of the enormous rate of growth that was made necessary by being second on the scene: its VHF network was started almost 20 years after the opening of Alexandra Palace; its UHF network became operational 5 years after BBC-2 – yet within 3–4 years the coverage of all three UHF programme channels in the UK was virtually the same.

To achieve this imposed challenging constraints on both engineering and engineering administration. Particular importance, for example, was attached to standardisation of station design to facilitate and speed-up construction and to simplify subsequent maintenance.

Equally important was the economics. This is reflected not only in the decision to design from the outset an entirely unattended and automatic network of UHF transmitting stations, but since the rate of construction would require very large capital investment, more would be achieved if building and equipment costs were optimised. Operational costs are governed to a marked degree by the number of manned control centres. For this reason the UHF network for the entire country – involving eventually over 400 transmitting stations – was designed in 1967 around only 14 colour control centres: recent developments, however, have made it possible to reduce even this number – and by the early 1980s it is expected that the whole network will be controlled and monitored from just four Regional Operations Centres.

With the network fast approaching 200 stations it seems hardly possible that everything started with the opening of the Authority's first Band III transmitting station at Croydon only in 1955. This station was a 'first' in many ways; indeed the first of the two 10 kW transmitters was an original laboratory prototype. The original station was built in a 'temporary' wooden hut but remained in service until 1969 when it was completely rebuilt. It was the first operational Band III station in the UK.

Further VHF main stations were built in the late 1950s and early 1960s near the main centres of population.

By 1964–5, approximately 98 per cent coverage of the UK population had been achieved from 21 high-power and a few relay stations. Already, however, significant gaps in the coverage had necessitated the planning of some lower power relay stations, and it had been realised that if these could be entirely automatic and unattended, considerable savings would be realised in the long term. The early IBA work in the use of un-manned stations had already underlined the value of this approach.

The introduction of unattended operation at the first relay stations at Selkirk in Scotland in 1961 was indeed a milestone from which there has been no turning back. Ultimately, 25 relay stations at various

power levels were built and, by 1970, the VHF network of 21 main stations and 26 relay stations provided 98·7% coverage of the United Kingdom.

Even before the last VHF station was completed however, a Government decision had been taken to duplicate the VHF 405-line coverage in UHF on the 625-line standard, which would be used for all colour transmissions, using the PAL system. The major differences of approach needed for such a project were the much larger numbers of stations required on UHF to achieve the required coverage and the need rapidly to achieve at least 70% coverage. The growth of both the VHF and UHF networks are shown in Table 1 from which will be seen the rapid growth of UHF stations and coverage, overtaking the number of VHF stations in less than 3 years – in spite of the 14 year 'start' of VHF.

The VHF Network

Before considering the evolution of UHF in more detail, it is relevant to note the main features of the VHF network as established by the IBA during the period 1955–70. The transmission system employed is CCIR System 'A', which is based on a 405-line interlaced picture with a field rate of 50Hz.

Positive modulation is used for vision, demanding maximum power output from the transmitters at peak



Fig.1. How it all started. Construction of the first IBA London transmitter at Beulah Hill near Croydon. This station opened on September 22, 1955 as the first operational Band III station. The single 10 kW transmitter was a laboratory prototype, the aerial an experimental 8-stack omnidirectional split array on a temporary 200 ft. tower with an effective radiated power of 60 kW. But it had a potential coverage of 10-million people.

white, with zero carrier output during the synchronising pulse interval. Both of these factors require some predistortion of the video signal. Video modulation is applied to the grid of either the penultimate or final amplifier and, in either case, a considerable video excursion or 'swing' is required. The transmitters employ thermionic valves throughout, tending to result in the usual limitations on reliability and stability of performance. In some cases, it has been found worthwhile to introduce modifications retrospectively to effect improvements, in particular the replacement of the original mercury vapour type rectifiers by modern solid state equivalents which has proved very beneficial.

The sound requirement of System 'A' also imposes stringent linearity requirements on the associated sound transmitter and dictates the use of separate vision and sound amplification, except at the lowest power relay stations. The sound and vision transmissions are combined in a combining unit which, typically, is a co-axial adaptation of the well-known Maxwell Bridge. The function of this unit is not only to isolate the vision and sound transmitters from one another and to combine their outputs, but

also to provide shaping of the vestigial sideband of the vision signal to achieve the required VSB characteristic for System 'A'.

Main VHF stations designed for manned operation were classified as high, medium or low power and transmitters ranging from 20 kW to 1 kW were installed. In some cases, transmitters are operated in parallel to achieve the required power, whilst in others a main/standby passive reserve system is used.

The building accommodation provided was, by modern standards, very generous. Accommodation for operational staff was of course necessary and entailed the provision of a canteen and kitchen, various offices, garaging facilities, sanitation etc. An example is shown in Fig.2.

The 'effective radiated power' (ERP) is the power transmitted in any given direction, taking into account the aerial gain in both the horizontal and vertical planes, in that direction. The distribution and feed arrangements of aerial elements are carefully adjusted to provide optimum coverage in wanted directions, whilst minimising radiation in directions towards other stations operating on the same frequency.

TABLE 1 GROWTH OF IBA TRANSMITTER NETWORK

DATE	VHF			UHF			NO. BUILT IN YEAR	UHF POPULATION COVERAGE	TOTAL STATIONS
	MAIN*	RELAY	TOTAL	MAIN	RELAY	TOTAL			
31.3.1956	2	—	2	—	—	—	2	—	2
31.3.1957	4	—	4	—	—	—	2	—	4
31.3.1958	6	—	6	—	—	—	2	—	6
31.3.1959	8	—	8	—	—	—	2	—	8
31.3.1960	11	—	11	—	—	—	3	—	11
31.3.1961	11	—	11	—	—	—	—	—	11
31.3.1962	16	1	17	—	—	—	6	—	17
31.3.1963	20	2	22	—	—	—	5	—	22
31.3.1964	20	2	22	—	—	—	—	—	22
31.3.1965	21	3	24	—	—	—	2	—	24
31.3.1966	22	8	30	—	—	—	6	—	30
31.3.1967	22	8	30	—	—	—	—	—	30
31.3.1968	22	10	32	—	—	—	2	—	32
31.3.1969	22	19	41	—	—	—	9	—	41
31.3.1970	22	22	44	8	—	8	11	60%	52
31.3.1971	22	25	47	17	—	17	12	78%	64
31.3.1972	22	25	47	27	22	49	32	85%	96
31.3.1973	22	25	47	32	49	81	32	93%	128
31.3.1974	22	25	47	39	77	116	35	94.5%	163

* Several of these stations have subsequently been modified for unattended operation. Two of the manned stations are at St. Hilary, S. Wales.

The first IBA transmitter (Croydon) opened on September 22, 1955.

The VHF network provides coverage of approximately 98.7% of the population to a standard less stringent than that used for UHF planning.

The vertical aperture of the aerial determines its power gain. Typically, a sixteen-wavelength-long aerial produces a power gain of 19. Concentration of power by this means, however, produces a narrow beam in the horizontal plane with attendant secondary lobes and nulls as the vertical angle increases i.e. close to the station. The main lobe is 'Beam Tilted' downwards from the horizontal by between 0.5° to 1°, depending on the mast height, so that maximum power is radiated to the horizon. The 'nulls' are angles of near zero radiation. These undesirable characteristics are eliminated either by feeding the two half-aerials with unequal power or by adjusting the powers fed to each aerial element to conform to a computerized calculation of a satisfactory radiation pattern.

The power is divided between the two halves of the aerial either by means of a 'Tee' transformer or a hybrid splitter. Individual transmitters do not

normally power separate half-aerials as such a system may deteriorate picture quality and introduce sound distortion in the 'null' areas.

As indicated, the aerials are split into two halves, and fed independently by separate coaxial cables from ground level. This system provides the facility for isolation of a damaged half-aerial and continued transmissions at reduced power during its repair.

VHF Relay Stations

Although the early VHF relay stations such as Selkirk have been well documented elsewhere, it is worth noting here that the economics of dispensing with operational staff were such that it was considered justified to install additional reserve transmitting equipment. Thus parallel 500 W equipments are backed up by a second identical set of equipment in passive reserve.

For relay stations, transposer equipment is provided



Fig.2. Stockland Hill, Devon opened as a manned VHF station in 1961 with buildings typical of those required in that period. Today there are both high-power VHF and UHF transmitters at this station but they are operated unattended from the regional colour control centre in Cornwall. Part of the building is now used for engineering training.

in place of the more usual sound and vision drive equipment. This receives the signal off-air from the parent station and by frequency conversion changes it down to convenient IF's between 30 and 40 MHz. Sound and vision IF signals are then separated, frequency converted to the new transmission frequencies and amplified in the normal way. For the early VHF relay stations, thermionic devices were again used almost universally, but the additional transmitting equipment installed, served to extend the interval between essential maintenance visits. The disadvantage is, of course, the amount of repair and maintenance work that has accumulated by the time a visit is necessary.

The provision of a large amount of spare equipment,

to be brought into service automatically as required, gave rise to the need to design a fairly sophisticated logic system and associated telemetry to the controlling main station. This system was based entirely on the use of electromagnetic relays and, although complex, has proved surprisingly reliable. Indications are sent to the control station along a rented Post Office telephone circuit and a number of remote control functions are possible in the return direction.

The later VHF relay stations installed were considerably smaller, of lower-cost and made use of solid-state techniques. The main feature of these stations is the use of a fully solid-state transposer, employing an up-converter to provide combined vision and sound

signals at about the 1 W level. These are then amplified in valved Class AB linear amplifiers to provide powers of either 10 W or 100 W to the aerial. By eliminating the need for a combining unit, using straightforward parallel operation and solid-state transposers, reliability is significantly improved.

The associated logic and telemetry were also simplified, although the control unit still employed gold contact, plug-in relays. Instead of rented circuits, normal subscriber telephone connections were used to the control station in conjunction with *Datafonic* telemetry. In practice, this simple and relatively low-cost arrangement has proved adequate in service.

This brief description of the Authority's VHF network would not be complete without a mention of the rebuilt Croydon main station which came into service in 1969. Although this was still a manned station, UHF planning and construction was already under way and it was clear that Croydon was to play a key part in the control of the UHF network in the area. The station was therefore completely rebuilt for unattended operation, in order that the staff would be able to give priority to control of the UHF service, with Croydon designated as one of the 14 regional colour control centres.

Three Pye 5 kW transmitters of established design were installed, although only two in parallel are needed to meet the power requirement. An associated logic system, based on solid-state techniques, selects any two transmitters for programme service with the third transmitter switched to test load but as a passive reserve. In the event of the failure of either of the transmitters in service, the reserve transmitter is run up into test load and then automatically phased with the one transmitter in service. When this process is complete, a third RF switch operates, switching the transmitter to aerial and so restoring full power transmissions. This custom-built system has proved extremely reliable over the years and has resulted in an almost 100% service record.

Because of the suburban environment of the Croydon transmitting station and its importance to the London region, considerable attention was given to the architectural design of the new building and the landscaping of its immediate surroundings. A feature was made of the transmitters by making them visible from the public road through large tinted glass windows, Fig.3. The success of this project may be

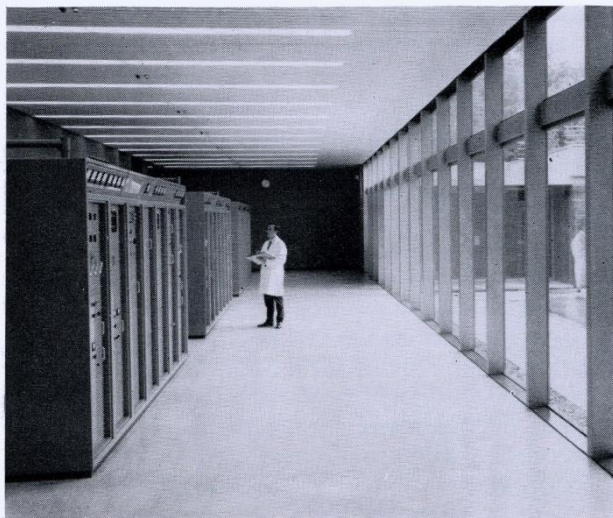


Fig.3. Croydon rebuilt. In 1969 Croydon was rebuilt not only as the VHF station for London but also to house the region's colour control centre. Because of the suburban environment special attention was given to the architectural design of the station and the transmitters (which now also include those for the London VHF ILR station) can be seen from the roadway through large tinted glass windows. The design won a Civic Award for 1969, the first television station design ever to do so.

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UHF Network

The Government decision announced in 1967 to duplicate both the IBA and BBC VHF 405-line services in UHF, prepared the way for ITV colour transmissions using the PAL system. BBC-2 was already in operation on UHF, and it was foreseen that three colour programmes might be available to the majority of the population by the end of the 1970s.

The 1961 Stockholm Plan had envisaged a four-programme UHF network in the UK and the detailed engineering planning has proceeded on this basis. Allocation and engineering of the fourth channel are as yet undecided, although there would be clearly engineering advantages if this was integrated with the IBA network.

Because of the difference in propagation between UHF and VHF, the total number of stations to achieve nominally the same coverage is inevitably much higher. Experience on VHF had shown that unattended operation was perfectly feasible for relay stations but little was known about high-power stations. However it was decided at the outset that the entire UHF network

of both main and relay stations *must* be both unattended and automatic in operation, although remote controls would be provided to override the automatic operation where necessary. Increased attention was given to the stability of performance and overall reliability requirements implied by the decision to operate such a large network in this way and it was fortunate indeed that the advance of solid-state techniques at this time was such that the limitations imposed by thermionic devices could be very largely eliminated. An example of the consequential effects of the tight specification limits called for in the equipment, was the need to stabilize the incoming supply mains to a higher degree than had ever been done on VHF stations. Automatic voltage regulators have therefore been employed almost universally to provide a supply voltage stable to within $\pm\frac{1}{2}\%$ of the nominal.

The First Phase

The first phase of the UHF construction programme had as a target the provision of a main station for all major centres of population by the end of 1971. This involved a total of twenty-eight stations to be installed and commissioned in less than four years. This represented an enormous rate of construction when compared with anything attempted previously. Some reorganisation and rationalisation of the Authority's Engineering Division was inevitable to meet this challenge, which primarily involved the Station Design & Construction Department. Assistance was provided in the field from the four Engineering Regions of the Authority; the South, based in Southampton; the Midlands, in Birmingham; the North, in Leeds; and (later) Scotland/Northern Ireland near Glasgow. Apart from the sheer magnitude of the technical problems involved in setting up a UHF network of this size in such a short time scale, aspects of planning, progressing and financial control all demanded specialist consideration as described elsewhere in this volume.

One major requirement for the new UHF service was that continuity and reliability of the programme should be of a very high order, so as not to mar its value for the viewers. The numbers watching on UHF rather than VHF, it was hoped, would grow rapidly if the project was successful from the start and enjoyed a good reputation. For this reason, it was decided to employ parallel operation of all transmitting equipment. In this way, in the event of a single fault anywhere in the chain, transmissions would continue without interruption, although possibly at a reduced

power. In order to alleviate the potentially serious maintenance problems arising from so much new equipment, particular attention was given to standardization. As an example of this policy, a standard design of equipment was ordered for twenty-seven out of the first twenty-eight stations constructed and these were installed in virtually standard accommodation. For the remaining station, Crystal Palace, where an ERP of 1 MW was required from aerials of limited gain (and the building was partly underground), the use of non-standard equipment of higher power was dictated by special circumstances. This was based on two Marconi 40 kW transmitters. The building layout is shown in Fig.4.

The Pye transmitter equipment is of two basic types, depending on the power level required. For about half of the stations, where up to 50 kW of transmitter power was required for vision (with 10 kW for sound), klystrons having five integral cavities were chosen – the first time such devices had been used in the UK. They have a power gain of 50 dB and therefore require only 1–2 W of drive, which could conveniently be provided by the solid-state drive equipment available at that time. For lower RF power levels, of up to 20 kW, klystrons with four external cavities of established design were chosen. The power gain of these devices was acceptable for this power level since drive equipment identical to that at the higher power stations could still be used.

Direct modulation of the UHF vision carrier is a main feature of the drive equipment. The principle employed is to terminate a circulator or 3 dB coupler with a mismatch (in the form of a varactor diode) which varies in sympathy with the video signal. Unfortunately, considerable unwanted phase modulation is introduced as well as the required amplitude modulation. This phase modulation has to be carefully removed by cancellation techniques in order to prevent the aggravation (in domestic receivers employing intercarrier sound detection) of intercarrier buzz.

Vestigial-sideband shaping is achieved between the drive and the klystron by means of a passive coaxial-type filter rather than in the vision/sound combining unit as on VHF. This enables the vision/sound combining-unit to be simplified, although additional rejectors are necessary to attenuate the unwanted 'mirror image' of the colour sub-carrier which tends to be generated by the non-linearities in the klystron.

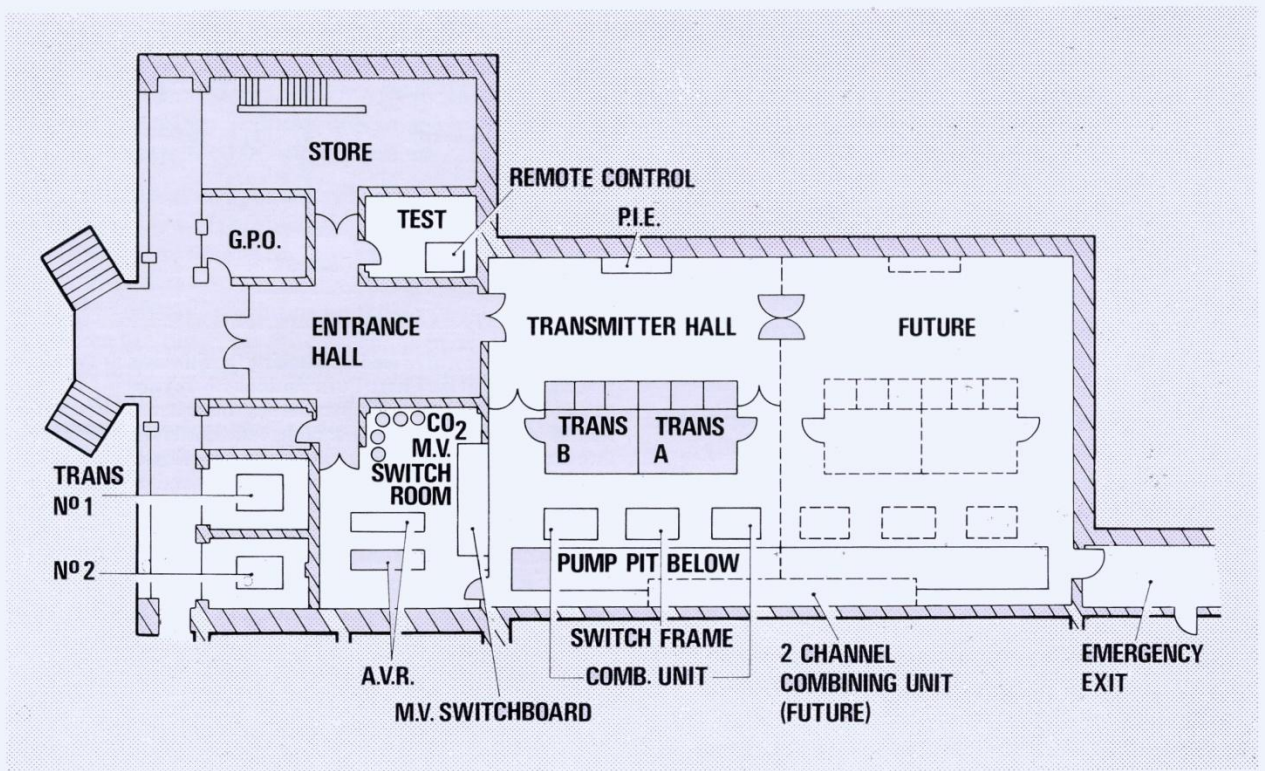
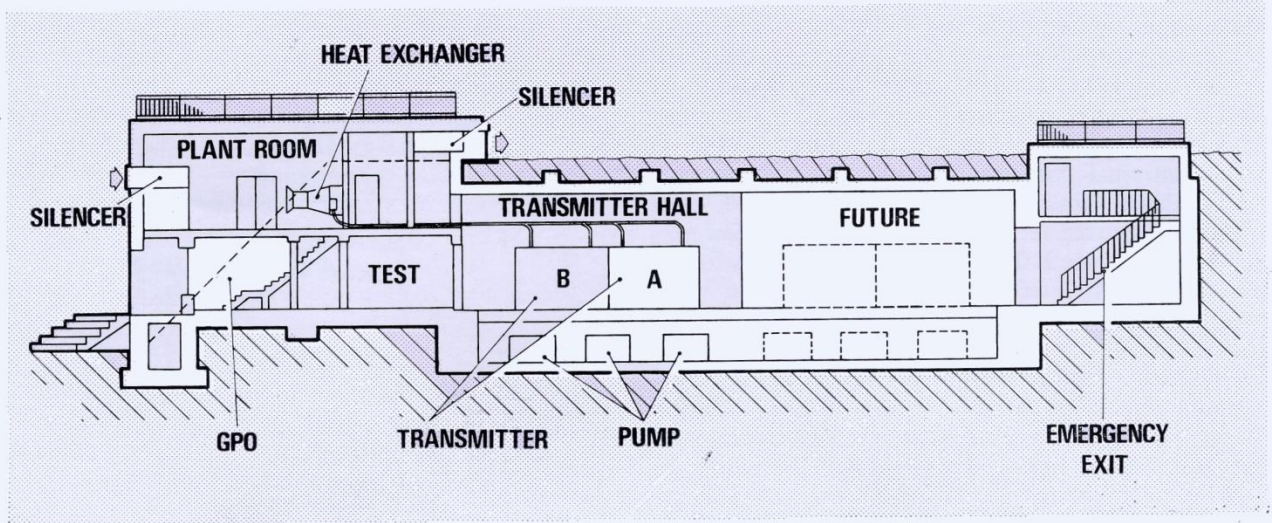


Fig.4. The 1 MW (ERP) unattended transmitting station at Crystal Palace with two 40 kW transmitters operated in parallel to make it one of the most powerful entirely unattended transmitting stations in Europe. Because of the semi-underground nature of the BBC site the IBA building provides space for transmitters for a fourth programme channel.

Considerable attention was given to the facilities for routing either of the parallel transmitters into test load or the aerial system, under fault conditions. Fig.5 shows diagrammatically what was provided. This gives maximum flexibility and versatility, without the complication of motorised switches. Single action, quick release U-links are used in all cases and the system has proved very satisfactory in service. The only disadvantage is that, because it is necessary for safety reasons to interlock the U-links with the transmitters, a short interruption to the service is required to change a U-link. The two output feeders from the switching frame go direct to the channel combining units and hence the aerial system, both of which will be described in the section on aerials.

Klystron Power Amplifiers

The transmitter power supplies are based on chains of avalanche-type silicon rectifiers with solid-state protection circuits. The main beam supply for the klystrons has the conventional 'three shot' automatic resetting system in the event of an overload. Solid-state logic is used throughout the control circuits, with the exception of certain heavy-duty contactors.

In order to obtain reasonable efficiency from the klystron amplifier, it is necessary to operate it over that part of its characteristic where it becomes increasingly non-linear as it nears saturation. Fortunately, with the 625-line system and negative modulation, this region of non-linearity mainly affects the synchronising pulse. Quite complex pre-correction circuits are required in the drive unit to compensate for klystron non-linearities, both in amplitude and phase. Group delay pre-correction also has to be introduced in the video circuitry to allow for changes in relative group delay throughout the transmitting equipment. This is particularly important if the quality of a colour transmission is to be fully maintained.

The klystron amplifiers employ vapour phase cooling to remove the considerable amount of waste heat from the collector. In the case of five-cavity klystrons delivering 25 kW of peak synchronising pulse power, the dissipation is of the order of 90 kW; for the four-cavity klystrons delivering 10 kW, about 40 kW. This heat is used to boil off water into steam; heat transfer is by means of latent heat of evaporation. Subsequently, the steam is condensed back to water in air-blast heat exchangers and the condensate returned to a reservoir tank. This system, although the most efficient in terms of heat removal, does introduce such problems as the prevention of freezing after

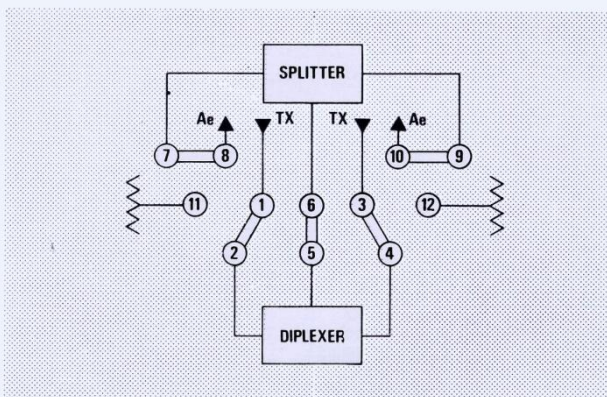
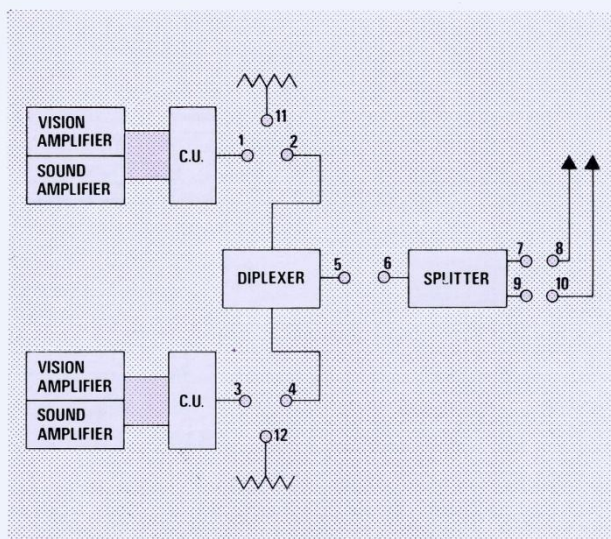


Fig.5. Arrangement of feeder switching facilities and RF U-link panel adopted at the Phase I UHF stations where two transmitters are operated in parallel but where it may be necessary for maintenance to route either of the transmitters into aerial or into test load. The use of single action, quick-release U-links avoid the complication of motorised switches and the system has proved very satisfactory in service.

shut-down and the maintenance of a high degree of purity in the water used in the system. Both of these design aspects have been the subject of considerable attention by the IBA engineers, both at the planning stage and in the light of experience gained with these installations.

Both types of klystron have proved capable of long operational lifetimes, several having achieved 15,000–20,000 hours. Although the initial costs are high, the costs per hour are not excessive.

Experience has shown that, as predicted, the tilting

mechanism provided for removal of the integral cavity klystron offers some advantages over the system used for the external cavity types, which involves removal of a truck assembly containing the electromagnet coils and the klystron. A hoist is necessary to remove this type of klystron, which then has to have its cavities removed and reassembled on the replacement klystron.

The Transmitter Buildings

The buildings provided for the original main stations were designed with the concept of dividing the technical area into three parts.

The *transmitter hall*, which accommodates the main transmitter cubicles, was made sufficiently roomy to permit easy manoeuvring of a large test equipment trolley and replacement klystrons. Attention was also given to the building finishes; for instance, the walls were plastered, a suspended false ceiling used to hide all overhead electrical trunking and conduits, and a fascia installed above the transmitters to screen steam pipes and vent ducts from view. The MV switchboard and automatic voltage regulators are accommodated opposite the transmitters and thus share a common floor area for maintenance purposes. The aim was to produce a transmitter hall having a low ambient noise level and a pleasant aesthetic design, even though it would be unattended in operational use.

The second area, designated as the *plant room*, is behind the rear wall of the transmitter hall and accommodates ventilation fans, cooling system pumps, ventilation ducts and the feeder switching frame referred to earlier. The building finishes in the plant room area are basic, no false ceiling is provided and the noise level is higher. Thermostat-controlled heaters ensure that the temperature does not fall below a minimum comfort level and that water in the cooling systems cannot freeze.

The third area accommodates the transmitter heat exchangers and offers only basic cover for essential maintenance purposes. No attempt has been made to apply any building finishes and no heating is installed. The heat exchangers self-drain back to reservoir tanks in the plant room. The noise level is, inevitably, very high.

The programme feed to such a station is normally by either microwave link or direct reception of another station using receivers of IBA design. Detectors are installed to sense the presence of synchronising pulses, which are used to switch automatically the transmitters on or off. All units in the vision and

sound input equipment are fully duplicated, with automatic changeover, but are otherwise of conventional design. This ancillary equipment is installed in separate racks in the transmitter hall and typically comprises the input equipment already mentioned, station alarm panel, a transmitter/remote control unit interface, as well as the remote control equipment.

The Local Relays

Even before the end of the first phase of construction, the initial planning for major relay stations had begun. These were clearly going to be required in large numbers to fill in the various gaps in the service areas of the main stations. All the service area planning in UHF is carried out jointly with the BBC because, from the start, it had been an inherent part of the plan that all UHF stations must be co-sited and should share the same mast or tower, and where possible, the same aerial.

The first relay stations were of two main types: one provided an ERP of approximately 10 kW; the other 2 kW. The transmitter powers required for these were 1 kW and 200 W respectively. As on VHF, the relay stations all employed non-demodulating transposer equipment. Vertical polarization is used for transmission, as opposed to the horizontal polarized signals from the main stations. This provides about 15 dB of discrimination against co-channel interfering sources (within the UK), assuming the viewer uses the correct aerial. In spite of the much larger number of channels available on UHF, their allocation is a major problem because of the number of times they have to be re-used to provide four-programme coverage on a national basis.

The relay stations are of much simpler design than the main stations. All the technical equipment, with the exception of the channel combining units and the receiving aerial splitters, is accommodated in one room. For the higher power level, paralleled 500 W amplifiers employing air-cooling tetrodes are used and for 200 W, paralleled, travelling wave tubes. Although air-cooling is simpler and permits a more compact installation, the problems of acoustic noise and air-filtering arise and impose constraints on both the equipment and building design.

All relay stations have been built in compact, secure buildings and accommodation has been allowed for transmitting equipment for the fourth programme, see Fig.6. Both the BBC and the IBA have access to a 'common area', in which the channel combining and

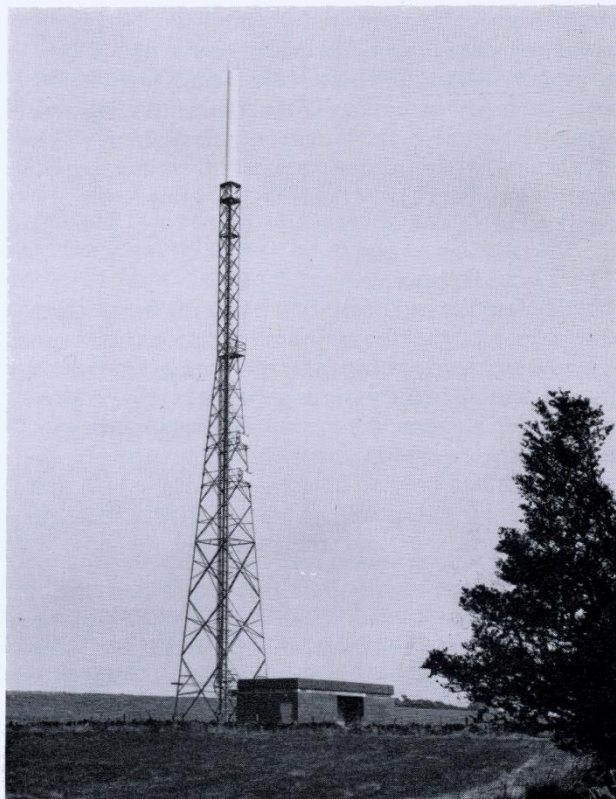


Fig.6. Representative of the many UHF stations in the early stages of the relay programme. This station at Wharfedale has an ERP of 2 kW with the enclosed transmitting aerials at the top of the 150 ft. tower and two trough receiving aerials mounted about half way up.

splitting equipment is accommodated, with doors leading off this to the individual technical areas. Normally, 150 ft. towers have been used as the support structures for the transmitting and receiving aerials. These have to be physically separated in order to provide approximately 60 dB of isolation.

The main technical problems encountered in relay station operation are those of signal-to-noise and non-linearity characteristics. It is essential that there is the minimum practicable degradation of signal-to-noise ratio on the incoming parent signal and, because common vision and sound amplification is universally employed, intermodulation between the two carriers and the colour sub-carrier must be kept to a minimum; this implies a very high degree of linearity throughout. Non-linearity is normally measured by means of a 'three-tone' test. For this test, cw signals are applied simultaneously to the aerial input terminal, corresponding to the normal vision

carrier, sound carrier and colour sub-carrier; a spectrum analyser is used to monitor the unwanted intermodulation products at the output of the equipment. A worst case level of 52 dB (reference to peak vision power) has been used as the standard limit for many years. This allows for some subsequent degradation before any discernible effect occurs on a colour picture. As for the main stations, attention has also to be paid to the group delay performance of the equipment. For maintenance purposes, it is interesting to note that the test equipment required to carry out full performance tests at a relay station is more comprehensive than that required at a main station. This in itself is an important design consideration, both from the point of view of ease of unloading test equipment and the space required in the transmitter hall for the test equipment trolley.

Control of both main and relay stations was originally planned from 14 Control Centres, located at the primary transmitting station in each of the Authority's programme companies' areas. These control centres were also responsible for technical quality monitoring of the pictures from the programme companies. At each Control Centre, a master telemetry equipment is installed, which is associated with a number of 'slaves' at the appropriate transmitting stations. The system, as we have seen, is primarily designed to be automatic and to raise alarms in the event of any change of state at an out-station, but a number of remote control functions are possible to override the automatic system and to take executive action where appropriate.

The Second Phase

Before the first phase of the UHF construction programme was completed, it was necessary to plan a second phase involving the provision of a further fifteen main stations and fifty relay stations. Generally, these were to be installed in areas serving lesser numbers of viewers, so that it was possible to review the original design considerations. A great deal of thought was given to ways and means of providing a thoroughly adequate service at a significantly reduced cost, when compared with the earlier main and relay stations.

The most important decision for main stations, arising from this line of thinking, was to adopt a passive reserve transmitter system rather than parallel operation. Furthermore, it was accepted that, in the event of a fault, the reserve equipment brought into

service could be of significantly lower power. A system employing three klystrons was therefore chosen, comprising a vision and sound klystron operating as a main transmitter in the normal way, with a motorized changeover system to select the third (identical) klystron for service as a combined vision and sound amplifier, in the event of a fault. This reserve amplifier must operate at a peak power some 7 dB down on the vision amplifier rating in order to ensure satisfactory intermodulation performance in the combined mode. The disadvantage of this arrangement is the interruption of the service for five minutes resulting from the minimum warm-up period for the reserve klystron. This was accepted in the interests of lower cost, bearing in mind the lower population coverage of these stations.

Another significant departure from the design philosophy of the original main stations was the use of IF, rather than direct UHF modulation. Although there are advantages and disadvantages associated with each method, it was considered that for optimum stability of performance, the low level IF modulator was on balance superior to the high level direct type, which requires the generation of about 10 W cw power at final carrier frequency. In addition, the IF arrangement offers a greater degree of standardization, since the only frequency-conscious element is the final local-oscillator chain. In practice, the IF modulation system has proved both more stable and reliable. Various design improvements, such as automatic level correctors, now make the setting-up procedure easier.

A detailed description of the IF drive equipment and the design of a complete Phase 2 main station is given elsewhere in this issue. The design objectives have been met and a high degree of reliability attained. When the time came to consider whether or not further design improvements or economies could be made for the later main stations, it was concluded that it would not be advantageous to attempt to introduce further changes; this was because the costs involved could not be justified by the potentially small benefits to be obtained. The design is, therefore, considered to be near optimum and has been adopted as a standard, although the power output from the reserve transmitter has been increased to 4 kW by compensation techniques.

Evolution of the design for the second phase of UHF relay stations proceeded along similar lines. First, ways and means of reducing costs were investigated

and the original decision to employ parallel operation reviewed. The outcome was a decision that, for economy, a passive reserve configuration would be adequate for the smaller centres of population to be covered and more compact buildings would be acceptable. Fig.7 shows the variation in the size of the buildings.

As far as the transposer and amplifier equipment itself was concerned, the most important decision was to discontinue the use of travelling wave tubes; instead to use UHF triode amplifiers. Although the TWT offers the advantages of broad-band operation, high power gain and long cathode life, it is a far more expensive device than the equivalent triode; it also requires complex power supplies and protection circuits. Triodes were also chosen for a number of relay stations on the grounds of simplicity and economy. In service, both types of thermionic amplifier have proved satisfactory. Tetrode and triode valve lives of about 5,000 hours are regularly achieved; for conventional power valves with closely spaced electrodes this is considered satisfactory.

Further developments in relay stations have taken place more recently. As might be expected, the trend has been towards a larger number of lower power relay stations of two main types, designed for 50 W and 10 W peak vision output respectively (typically providing about 500-watts and 100-watts ERP). Such stations serve relatively small pockets of population and the IBA, in conjunction with the BBC, has been giving the question of 'cost per viewer served', considerable thought. At present, un-served areas down to 1,000 people are taken into account at the planning stage; clearly, if the total cost of such relay stations is high, an investment of several pounds per viewer per channel is involved. An important policy decision, resulting from these cost effectiveness studies, was that the two broadcasting authorities should jointly share a single technical equipment area at the 50 W and 10 W relay stations. Although there are certain operational disadvantages in such an arrangement, these are more than offset by the reduction in costs.

For the 10 W stations, the equipment is all-solid-state. Modern devices are available which permit this power to be obtained from four transistors operating in quadrature, with their outputs combined by 3 dB couplers. The other main feature of the transposer equipment is that no test equipment is required on site. A built-in meter is provided,

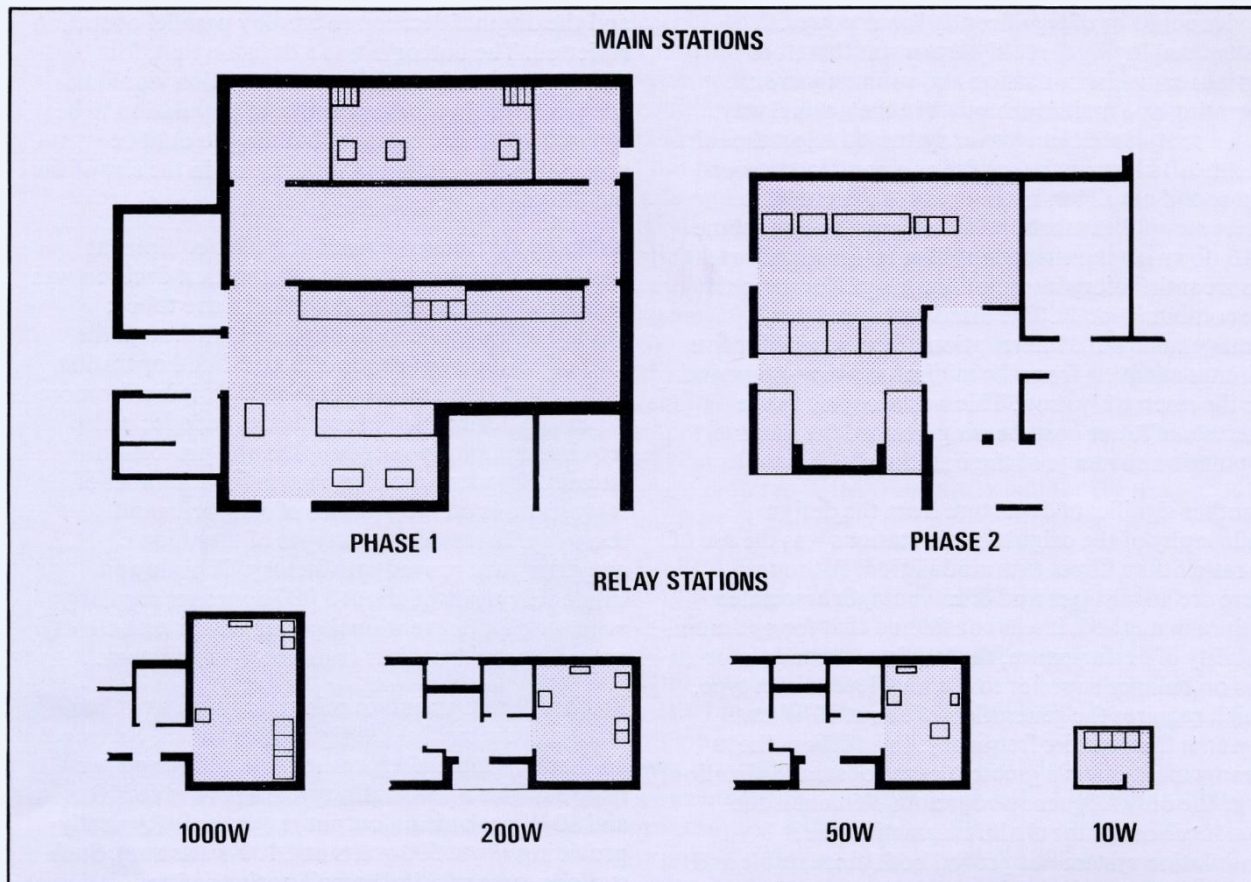


Fig.7. A comparison of the floor area of unattended UHF transmitting stations showing the significant reduction in size of the Phase 2 main stations and the very compact 'container' units for the all-solid-state 10-watt local relays.

indicating the faulty sub-unit, which is merely exchanged with spares carried by the mobile maintenance team. This facet of the design means further economies can be made in the access track provided, since, if necessary, the replacement spares can be carried a short distance on foot. Furthermore, no space need be provided for a test equipment trolley. This has led to a compact type of prefabricated building, which can be readily transported to site on a special vehicle. It is envisaged that ultimately the installation will be virtually completed before shipment.

The Future

From the beginning, a steady process of evolution has taken place, starting with the VHF network and continuing with duplication on UHF. As already mentioned, UHF coverage to achieve full duplication will not be complete until the early 1980s and the

process of evolution will certainly continue. The greater part of the remaining construction work will involve further 50 W and 10 W stations, with a number of even lower power, perhaps as low as 1 W. It is hoped that with the advance of semiconductor technology, the majority of the remaining 50 W equipments will also be fully solid-state. Thus, in conjunction with the low power transposer design already in use, no on-site maintenance will be necessary. This means that further reductions in building size and the use of prefabrication techniques will be possible on a wider scale.

As far as future developments in ancillary equipment are concerned, a continuing trend towards further automation is envisaged. Off-air monitoring, even of primary main stations, is likely to disappear and the use of automatic monitoring techniques may become universal. As a result of a special relaxation of the

Post Office requirement for verbal announcements, electronic dialling and answering units will replace the electro-magnetic tape equipment in the role of alarm-raising through the public telephone network. This is expected to result in a significant improvement in overall reliability.

Attention is also being given to the VHF network, much of which is based on equipment more than ten years old. The feasibility of unmanning all the VHF main stations is being investigated, since this would allow operational staff to be redeployed on maintenance duties. A possible rearrangement of all the control and telemetry equipment into just four Operational Centres for the entire UK is also being considered; this would entail a considerable amount of work and additional capital expenditure. Nevertheless, the potential savings (even over a relatively short period of time) may fully justify the exercise. Certainly a more flexible and streamlined arrangement would result.

Planning and Control of Construction Programmes

Synopsis

Building a transmitting station to a timetable requires efficient engineering administration as well as electronics. Project planning, progress reporting, budgetary control, contract preparation, documentation are all necessary if a high-power main station or a low-power relay is to come on

air to time, though such aspects of station construction are often forgotten in the literature. In this section an account is given of how this work is tackled within the IBA to keep under review the planning and progress of some £3-million annual capital investment in transmitting stations.

Such capital-intensive activity as the construction of transmitting stations (for which the IBA currently has a total annual commitment of approximately £3,000,000) requires a number of administrative and other engineering support services. These services include project planning, progress reporting, budgetary control, contract preparation, installation design/layout and technical handbook preparation/production. Within the IBA, all of these activities are combined in one section. The number of stations built in recent years reflects increasing administrative work undertaken by this planning and control section.

A considerable variety of work is undertaken. Drawings are prepared, varying from small site plans to the complex logic diagrams associated with telemetry. The planning and progress techniques used range from simple schedules and bar charts to computerized PERT systems. Financial control is maintained over individual budgets, which may vary from £10,000 to £300,000, and orders for equipment costing from £10 to £1,000,000. Each main and relay station requires a separate handbook, whilst certain specialised equipment designed within the IBA also requires maintenance documentation.

Planning

The construction of new stations is authorized in 'phases'. Early phases each contained an average of 30 stations to be built over a two year period. With some 19 out of 20 people now within range of one of the existing UHF transmitters, the prime requirement

today is for small relay stations 'filling in' the gaps in coverage. These stations are being built at the rate of about one a week, and this will continue for about five more years. Fig.1.

The order in which a complete phase of stations is to be built is decided at Authority and senior management level. It is then the responsibility of the planning staff to propose and draw up a cohesive and efficient construction programme.

The construction of each station follows a basic pattern which, often with the aid of network techniques, is plotted out in the form of a bar chart. The bar chart serves as a basis for discussion among the engineers responsible for the supervision of station construction. Close liaison with the various engineering sections is necessary in order to detect any deviations from the standard construction pattern and to ensure that resources are not over-loaded. Care is taken to ensure that the installation workload is evenly spread over the four regions into which the country is divided for administrative purposes. This is important as regional staff become increasingly more involved in the installation work. Discussions with the BBC are required in order to clarify requirements and exchange information.

When all factors have been considered, a bar chart is drawn up. This shows the anticipated duration of each major on-site activity, i.e. building, power, mast and aerials, transmitters and remote control. The bar chart is widely circulated for planning purposes.

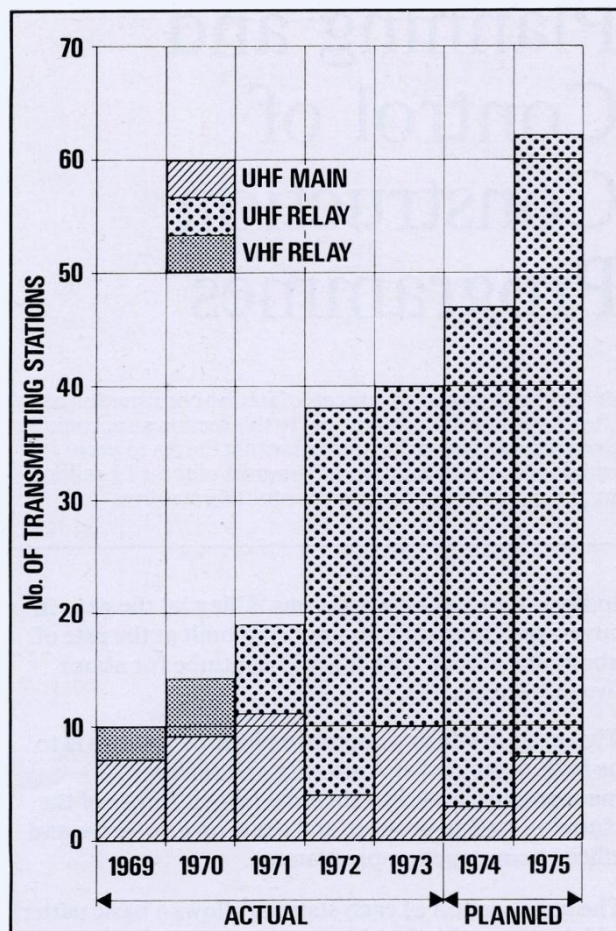


Fig.1. The start of the UHF network in 1969 resulted in a rapid expansion of the constructional programme, currently representing almost one new station per week and more than this in 1975. The construction of each station follows a basic pattern which can be administered by means of network techniques presented in the form of a bar chart.

The planning activities outlined above occur 18–24 months before the anticipated completion of the station. Preliminary information on delivery details and installation dates reaches the system 3–6 months after the planning bar charts are circulated. A typical UHF main station requires about 15 months on-site installation work; a relay about 9 months.

Drawings

The principal function of the station drawings is to specify the various requirements for each new station. For example, each station has a drawing that defines the equipment used in the electrical supply system. The drawings are supplied to outside

contractors to enable them to submit competitive tenders. When a station has been commissioned, these drawings, amended as necessary, become the 'as installed' record for the equipment.

Work in the drawing office is broken down under various headings, as follows: (1) Main stations; (2) Relay stations; (3) Links; (4) Unmanning of the VHF stations; and (5) Control centres.

Under any of these headings, drawing effort is required on site plans, electrical/electronic installations and mechanical installations.

Draftsmen are required to liaise with members of the engineering project teams to obtain the information necessary for producing definitive drawings. Thus a senior draftsman responsible, say, for UHF relay stations will be involved with the project team concerned, attending liaison meetings and visiting sites as necessary.

Throughout the station construction programme, there has been a steady increase in the amount of drawing effort devoted to telemetry and control systems. The size of a station is no real guide to the drawing effort required. This is illustrated by the comparison of the capital costs and the drawings required for a main and a relay station:

	<i>Capital Cost</i>	<i>No. of Drawings Required to Define Equipment</i>
Small Relay	Up to £30,000	Up to 12
Main	Up to £300,000	Up to 25

Contracts

The first stage of the financial preparations for a new station is to write a detailed estimate of capital expenditure, using costs provided by the specialist sections. When each estimate has been authorised by the Authority, a start is made on the procurement of equipment. In some cases, for example when prices or delivery can be improved by forward ordering, advanced dispensation is sought, so that orders can be placed for future stations for which detailed estimates do not yet exist.

Fig.2 shows how the budgets for a typical 10 W station and a Phase 2 main station are divided between the different technical equipment areas.

Before a firm order can be placed for any item, the sections with technical responsibility must obtain

permission to use the money previously authorised. This is done by preparing a 'Capital Expenditure Proposal' which specifies the equipment required, its supplier and its cost. The proposal must be acceptable on both commercial and technical grounds and must be within the authorized budgetary limits, before it can gain approval at the appropriate engineering management level.

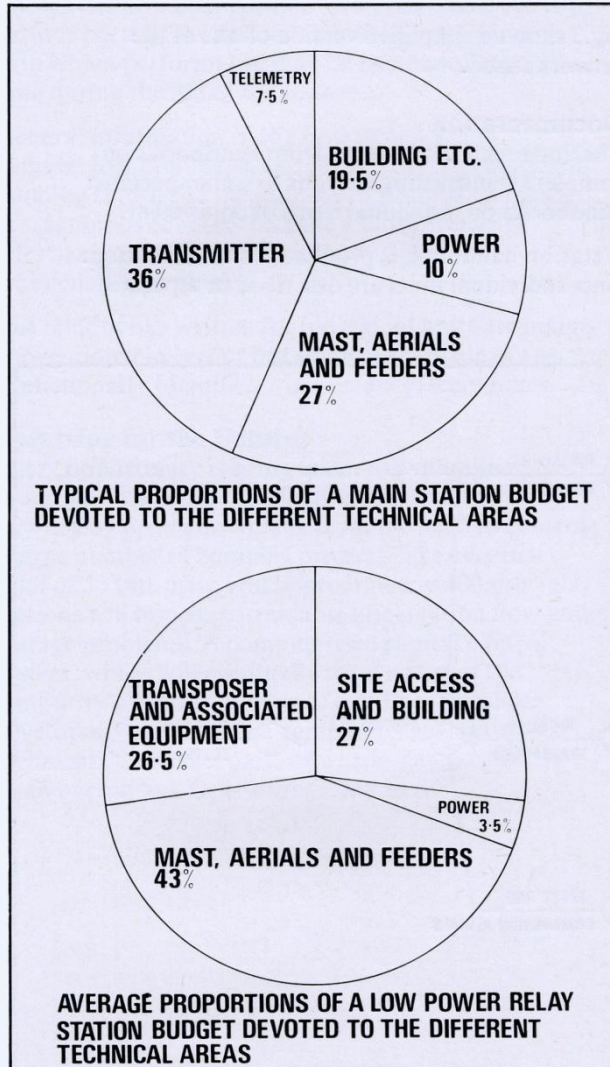


Fig.2. The budgets for main and local relay stations show marked differences with the proportions for aeriels and transmitting equipment approximately interchanged. Before contracts are placed a 'Capital Expenditure Proposal' is prepared, specifying equipment, suppliers and cost. All proposals have to be acceptable on both commercial and technical grounds before the equipment is ordered.

Ordering of equipment and materials is carried out by means of either a Purchase Order or a Contract, the former normally being used for 'off the shelf' equipment and the latter for equipment requiring some design or installation work on the part of the contractor.

Contracts issued include all the relevant details, special conditions and the nature of the contract, i.e. whether it is fixed price or with contract price adjustment. In common with similar organisations, the IBA is subject to procedures required to bring about a satisfactory and sensible contract; for example, a contract must be in the interests of all parties and the maintenance of good working relationship between purchaser and vendor is of prime importance.

All contracts are based on the Conditions of Contract recommended by the IEE and I MECH E or the ICE although these conditions are qualified by the IBA Conditions of Contract.

Progress

A flexible progress monitoring and reporting system is required to cope with the changing pattern of station construction: over the three years 1971-73 the number of stations under construction at any one time almost trebled (it has trebled if ILR radio stations are taken into account).

Progress information is collected in various ways including normal day-to-day liaison with individual engineers.

Separate monthly progress meetings are held for UHF main stations and for UHF relay stations. The engineering sections are responsible for updating a progress sheet for each station every month. These sheets give details of major activities at each station, together with planned completion dates.

Progress information is circulated within the station design and construction department by way of bar charts used in the planning phase. They are updated and re-issued monthly following the monthly progress meetings. Progress reports are issued weekly and monthly. The weekly report provides an opportunity for everyone to see the progress of those stations that are in the later stages of installation, i.e. 3-6 months before completion. The monthly report, circulated throughout the IBA, gives predicted completion dates for all stations within the constructional phase.

Progress sheets updated by the engineering sections provided a satisfactory means of collecting detailed progress information for a number of years, but,

owing to the current increase in the number of stations under construction, this system is proving to be too laborious and a new system is now evolving.

A network analysis system, in which the progress of UHF stations was monitored and a computer used to calculate completion dates, was tried several years ago. However, this system proved to be too inflexible; while the data preparation time, coupled with the necessity for batch processing, often resulted in an out-of-date print-out.

Based on this experience, a new system of network analysis has been devised, taking advantage of the powerful data processing facilities now becoming available. These will include visual display units and input keyboards, providing a direct on-line link to a computer.

Networks have been prepared linking the key installation activities for each standard type of relay

station. With minor amendment, one of these networks can provide all the progress information required for any relay station.

The construction programme can be presented in various ways by the computer, while the effect of delaying any item of equipment can be displayed or printed out for action or future reference. A trial run of this system on ten stations under construction has proved very successful.

Fig.3 shows a simplified version of one of the networks used.

Documentation

The documentation ranges from handbooks on complete transmitting stations to some specialist handbooks on individual items of equipment.

A station handbook is produced for each station. Since individual units are described in separate

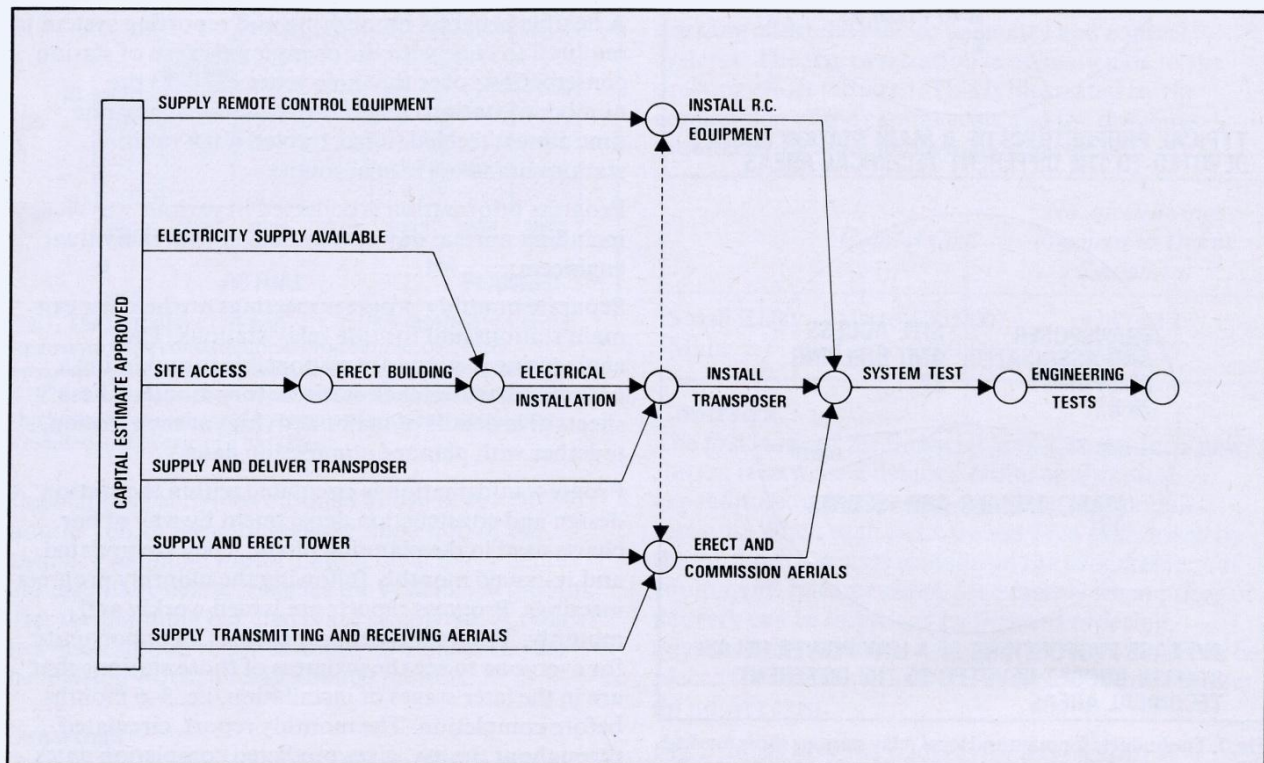


Fig. 3. A simplified 'network' showing the relationship of the main basic activities involved in the construction of a typical UHF relay station. In practice a network prepared for the input of progress on to the computer will contain some 50 key activities. The construction programme can be presented in various ways by the computer, and the effects of any delays in any part of the programme can be displayed or printed out. A trial run of computer analysis of networks has proved very successful in monitoring the progress of a batch of 10 stations.

technical handbooks, the station handbook treats all the technical equipment in a station as a system, i.e. the individual units are black boxes.

Separate sections in the handbook deal with general details, equipment layout, the building, power supply, transmitter, masts and aerials and telemetry/automation. Test results obtained at the time of the station's commissioning are included in the handbook.

These results indicate the performance obtained from various parts of the system and provide a reference with which performance may be compared at any time during the life of the station.

General information in the station handbook includes location maps, site plans, coverage map and building layout. As the number of stations increases, the station handbooks become a most necessary reference source, apart from their value for maintenance purposes.

The handbooks written for individual units are mainly conventional in layout but some use is made of FIM (Functionally Identified Maintenance) techniques.

Preparing for the Future

Every opportunity is being taken to exploit the available data processing facilities to deal with the day-to-day problems arising from the need to control a large number of complex projects. The eventual total of 50 UHF main and approximately 400 UHF relay stations will impose formidable information flow and storage problems. A computerised capital control system, which will eventually form a part of the Authority's overall 'Finance Data Base', is under development; so also is a computerised station technical details file, parts of which may contribute to an overall 'IBA Operations Data Base'.

A Recent Design for 11 kW Transmitting Stations

Synopsis

By the end of 1971 all the first phase of the IBA UHF network of unattended high-power transmitters were in operation, ranging in power from 100 kW ERP to 1000 kW ERP, and all based on parallel operation of the main transmitter units to provide virtually uninterrupted service. But the second phase of the programme gave an opportunity to consider

how, for the less 'crucial' transmitters, capital costs could be reduced by other 'fall back' systems, and at the same time general reliability could be improved still further and maintenance reduced.

This led to the introduction of a new design of 11 kW station (ERP usually 100 kW) with a combined sound/vision reserve amplifier.

For the second phase of the UHF main station construction programme, it was decided, in the light of experience gained with the first phase, to introduce a number of design changes. The main objective was to reduce capital costs, to further improve reliability and so reduce maintenance.

It is IBA policy to provide reserve transmitting equipment at all UHF main stations. This not only permits continuity of service in the event of breakdown but also allows maintenance to be carried out during programme hours. There are two basic configurations by which this can be achieved.

1. Duplicate active vision and sound transmitters operated in parallel.
2. Duplicate transmitters operating in a main/passive reserve mode.

Parallel Operated Transmitters

In a parallel operated station, each transmitter operates at half the required total power. However the cost of a transmitter operating at 5.5 kW (vision) is little different from one operating at 11 kW as the klystrons available for the lower power are very similar in design and hence cost. For a full parallel operated transmitter installation a total of four klystrons have to be used (2 vision and 2 sound).

Main Passive Reserve Transmitters

There are a number of possible configurations of transmitters to provide this mode of operation:

- (1) Main transmitters with full power reserve.

- (2) Main transmitter with low power combined vision and sound amplifier reserve.
- (3) Multiplexed klystron amplifiers.

Main with full power reserve: There is little economic advantage in providing this mode of operation over paralleled amplifiers since four klystrons are still required.

Main with low power reserve: Normally passive reserve equipment is provided with an output power about -6 dB compared with the main equipment. It has been shown¹ that if a klystron amplifier is derated by approximately 7 dB the linearity of the device allows common vision and sound amplification with acceptable intermodulation performance. If the same klystron is used for the reserve equipment as for the main 11 kW vision amplifier, an output power of 2.2 kW vision and 440 watts sound may be obtained from a single klystron. This means that a total of only three klystrons can be used to provide 11 kW vision and 2.2 kW sound from the main transmitter, and 2.2 kW vision and 440 W sound from the reserve equipment. This is little different from that obtained from a full parallel arrangement when one transmitter fails (since with the combining equipment normally provided, half the remaining transmitter power is fed to the aerial and the other half to the balancing load of the combiner). In addition to the lower capital cost of a klystron equipment a smaller and hence cheaper building is possible.

Multiplexed klystron amplifier: In this system only

two klystrons are used with separate power supplies. Normally one klystron is used as a vision amplifier and the other for sound. In the event of either amplifier failing, the other acts as a low power combined vision-and-sound amplifier. However it is necessary that each klystron be carefully adjusted to act either as a vision, sound, or combined amplifier. This drawback, combined with the necessary control logic, high voltage switching, and complex RF switching, makes maintenance more difficult, and for these reasons this system has not been adopted by the IBA.

Another important consideration is the running cost of the equipment. The reduced amount of equipment operating in a main/reserve system is cheaper to run than a parallel system and requires less maintenance. After consideration of the possible options, with their various advantages and disadvantages, the IBA chose

for Phase 2 a main/reserve system with a low power reserve for common amplification of vision and sound signals. This includes a single RF feeder switch controlled by a fully automatic change-over system which selects the preferred transmitter to the aerials or test load.

Transmitter and Building Layout

For the first phase of UHF main stations (which were generally of higher power), parallel transmitters were employed, as described earlier. A reduction in capital expenditure for the Phase 2 stations was achieved by building only one room which is effectively divided into a transmitter hall and a plant room by the transmitter cabinets.

The heat exchangers are situated in the plant room, drawing in and expelling air by means of a chimney arrangement situated at the end of the building. The chimney eliminates the need for holes in the roof. A considerable saving in space has been achieved by packaging the heat exchanger, air filter, motorised louvres and blowers, in a single acoustically-treated 'cooler unit' enclosure. By this means considerable success has been achieved in reducing the acoustic noise. The combining unit and switching frame is situated in the centre of the plant room. The water tanks and test load are installed behind the combining unit.

This layout of the transmitters and plant is compact and occupies an area of approximately 35 m².

Cooling System

The design of the transmitter cooling system was simplified to reduce maintenance. No water pumps are used either for transmitter cooling or for the test load. To remove the waste heat from the klystron collectors, an entirely self-circulating vapour phase cooling system is used. The collector is immersed in water which is allowed to boil and the resulting steam is passed to a forced air cooled heat exchanger. The condensate returns directly to the klystron boiler. Water losses are made good by detecting the water level in the boiler and operating a solenoid valve, as necessary, to let in water from a separate reservoir tank. The main heat exchanger cooling fan is also used to provide cooling to the transmitter cabinets as well as to ventilate the transmitter hall and plant room.

One notable feature of the design of the cooler units is that for low external ambient temperature, air to the heat exchanger is maintained at a constant 20°C

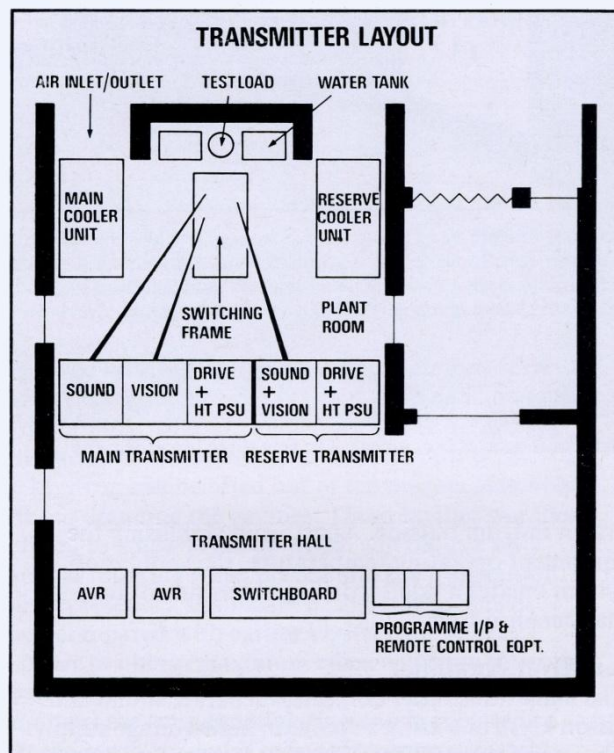


Fig.1. For the Phase 2 main stations the transmitter hall and plant room were formed within a single area by placing the main and reserve transmitter cabinets to form a dividing 'wall'. The heat exchangers are in the plant room, drawing in and expelling air by means of a chimney outlet at one end of the building, so eliminating the need for holes in the roof. The single acoustically-treated 'cooler-unit' enclosure has successfully reduced acoustic levels.

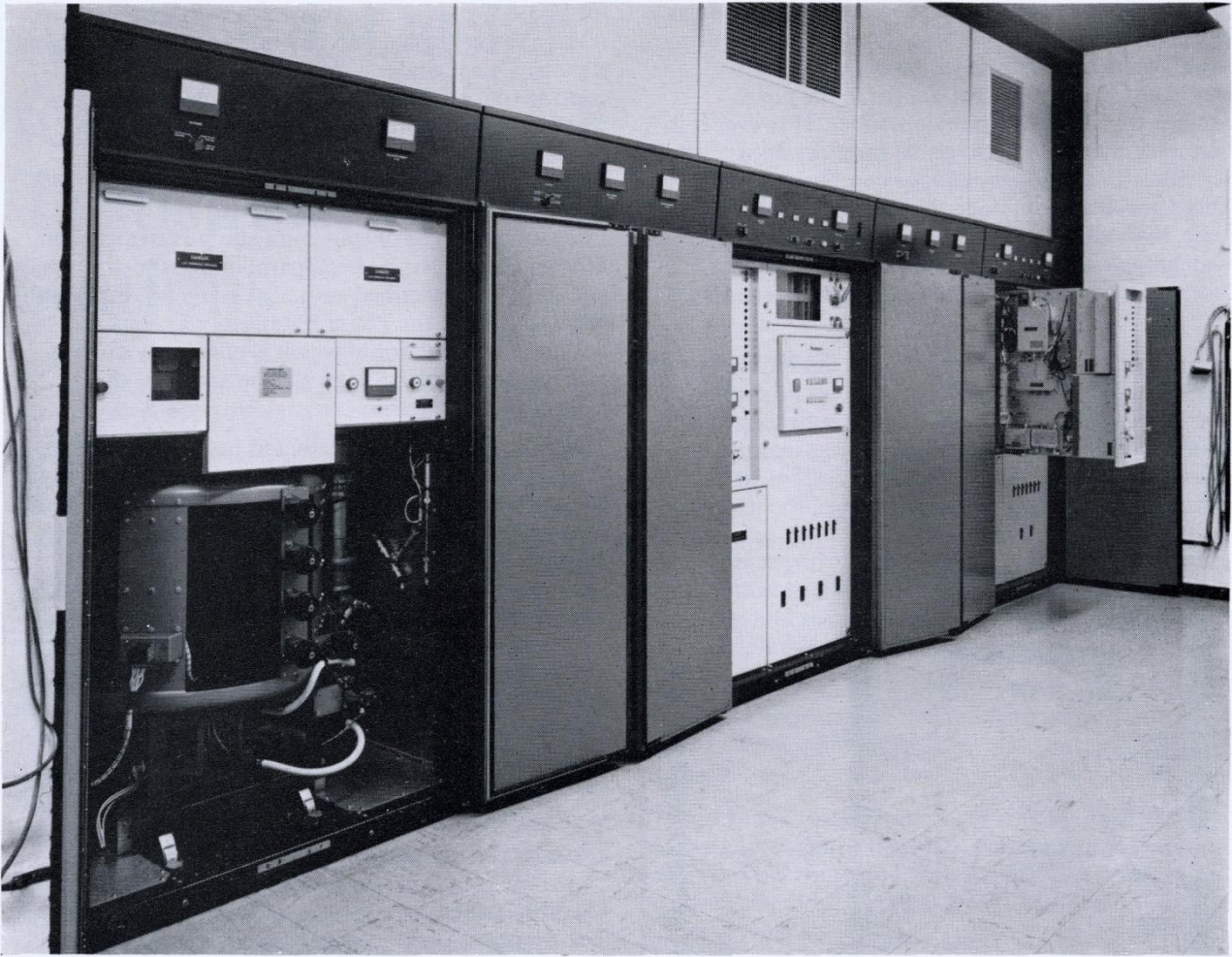


Fig.2. One of the Phase 2 transmitter installations with the sound klystron unit nearest the camera. The first three bays form the main transmitters and the final two bays the reserve transmitter.

by a system of motorised louvres. Some 2200 cubic metres per hour (m^3/h) ($1300 \text{ ft}^3/\text{m}$) of this air is directed to an automatic roll filter and $1700 \text{ m}^3/\text{h}$ ($1000 \text{ ft}^3/\text{m}$) passes directly to the transmitter cabinets for general cooling. The remaining $500 \text{ m}^3/\text{h}$ ($300 \text{ ft}^3/\text{m}$) of air is increased in pressure by an additional blower and fed to the klystron cavities before being expelled into the transmitter cabinet. The temperature stabilisation has significantly contributed towards overall stability of performance. After cooling the transmitter cabinets, the total $2200 \text{ m}^3/\text{h}$ of air is expelled either into the transmitter hall or outside the building. (See Figure 3.) This system serves either to warm the building with the waste heat from the transmitter, or to cool it with air

drawn in from outside. Apart from stabilising the equipment operating temperature, the ventilation system creates a good working environment for maintenance staff.

Klystron Amplifier

The main transmitter comprises separate sound and vision klystrons using a common high-voltage supply. The use of separate amplification allows maximum power output and optimum efficiency – of the order of 30% – to be obtained. Amplitude and phase pre-correction of the vision drive signal is necessary to compensate for the non-linearities of the vision klystron amplifier.

The K370A klystrons with four external cavities are

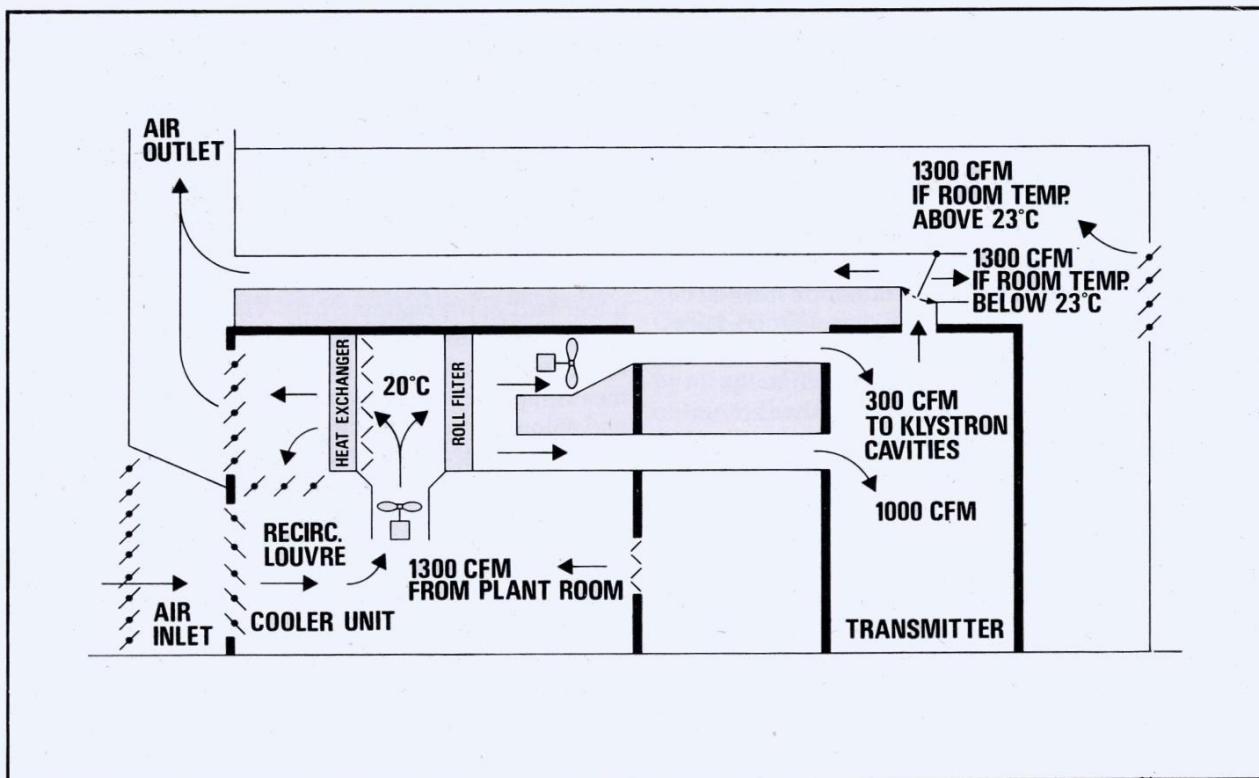


Fig.3. The cooling arrangement used in the 11 kW Phase 2 stations. Air to the heat exchanger is maintained at a constant 20°C by means of a system of motorised louvres. The effect of temperature stabilisation has been found to contribute significantly to overall stability of performance. The system either warms the building with waste heat from the transmitter or, in summer, cools it with the air drawn in: this creates a good working environment for both equipment and any maintenance staff visiting the station.

improved versions of those used in a number of the Phase 1 transmitters. For fast warm up and good long term stability, all four cavities are forced air cooled with the air stabilised to 20°C. In the event of failure, the klystron can be lifted out of the magnet assembly without detuning the cavities. These cavities can then be fitted to a new klystron which will require only minimal retuning when placed into the transmitter. This represents a significant design improvement when compared with earlier klystron amplifiers. In order to obtain maximum efficiency from the sound klystron (which has the same HT supply as the vision amplifier) the sound modulating anode is biased so that the beam current is reduced to approximately 1/5th that of the vision amplifier. The bias potential is derived from a resistor chain fed from the main HT supply. The sound klystron is tuned for only a 2 MHz bandwidth and driven to saturation for optimum efficiency.

In the case of the main transmitter, both klystrons are

controlled from a single control unit which provides the necessary heater warm-up delay and overload protection circuitry. When the transmitter control is switched to "remote" the transmitter comes under the control of the automatic change-over logic and the telemetry systems.

Drive Transmitters

An IF system of modulation is employed to drive the klystrons. In the main transmitter the sound and vision paths are entirely separate, as shown in Fig.4. One volt of composite video signal having a picture/synchronising pulse ratio of 70/30 is required at the vision input terminal. This is fed into a video unit where the video processing and clamp pulse generation are carried out.

The clamp pulse generator employs techniques to reduce the possibility of spurious clamp pulse generation from 'drop outs' caused by scratched video tape, interfering pulses, and low frequency distortion. Precautions are also taken to reduce the effect of

random low frequency noise produced by clamping to a signal containing high frequency noise.

The video processor first cancels the original sync pulses. All subsequent clamping is then carried out during the blanked sync interval, thus eliminating problems of clamping during the colour burst. The video unit corrects the picture/sync pulse ratio (if necessary), provides differential phase correction and peak white limiting, and removes video frequencies above 5.5 MHz. The out-of-band radiation filter is corrected for group delay, and additional group delay correction is provided for the sound/vision combining unit which is external to the transmitters. Finally, constant amplitude reconstituted sync pulses are reinserted in the last video amplifier, immediately after the blanking process necessary to eliminate disturbances arising from the sync cancellation and subsequent clamping.

The clamped video signal is then fed to a diode ring modulator, together with the output from a 38.9 MHz oscillator, before passing through the vestigial sideband (vsb) filter. The vsb filter is followed by three active group delay correctors which are sufficient for a System I vsb transmission.

After vsb filtering, the IF is fed to the differential gain correctors where broadband correction for non-linearity of the klystron amplifier is carried out. The klystron non-linearity results in low frequency sidebands near the carrier of a vsb signal being compressed more than high frequency sidebands further away from the carrier. This is because the peak envelope power in the double sideband region of the vsb signal is greater than in the single sideband region, so that the double sidebands are operating on a less linear part of the characteristic. The differential gain correctors produce the complement of the klystron characteristic and enhance the double sidebands. This means that, in principle, separate line time linearity and colour sub-carrier differential gain correctors are not required. However, because the frequency response of a klystron varies with output level, the linearity and differential gain characteristics do not always coincide. A further linearity corrector is therefore included to eliminate these minor differences. The differential gain correctors operate by reducing the negative feedback of an amplifier depending on the amplitude of the IF. The threshold at which each corrector operates is continuously variable. The design of the differential gain correctors has been improved by

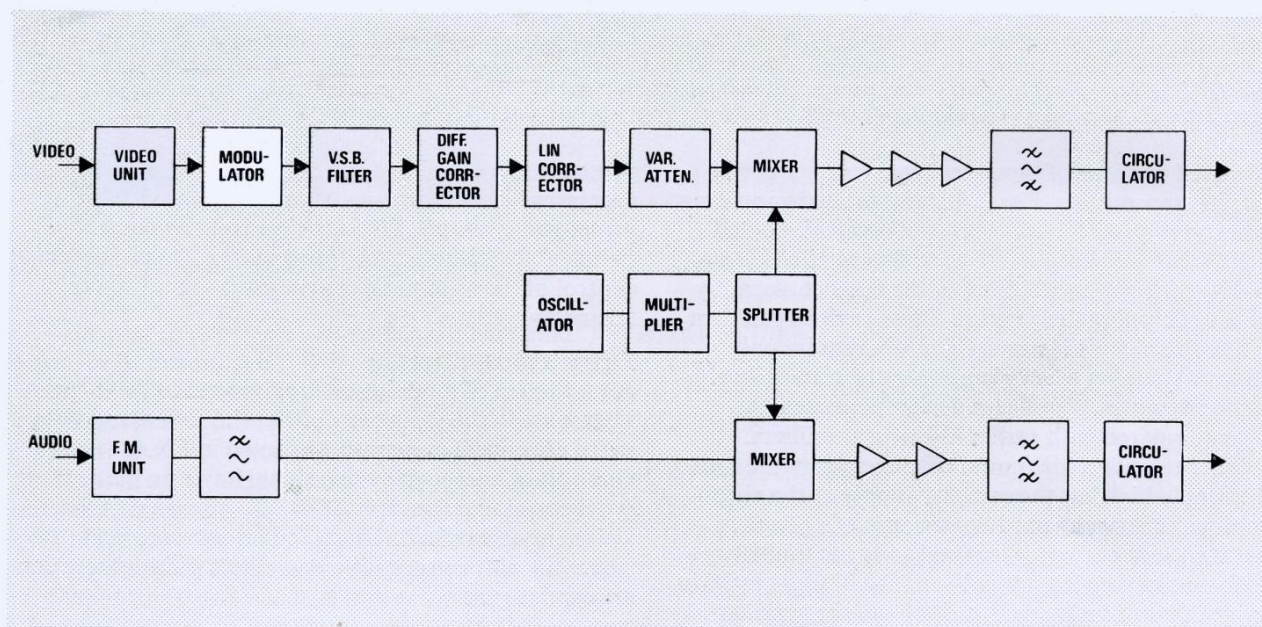


Fig.4. Block outline of the main transmitter drive arrangements for video and sound. One-volt of composite video signal input is processed and amplified to provide an output of 1.5 watts. On the sound signal frequency modulation is carried out by means of a variable capacitance diode forming part of the tuned circuit of a 32.9 MHz oscillator having automatic frequency control. The injection signal for the final sound and vision mixers is derived from a 5-watt signal applied to a step recovery diode from which the eighth harmonic is recovered and filtered.

the addition of an automatic gain control loop of long time-constant. This stabilises the output level of the corrector so that as correction is applied the modulation depth remains constant.

After precorrection, the IF passes to a variable gain IF amplifier. The gain of the amplifier is controlled by the amplitude of a sample of the blanking level sensed at the output of the vision klystron. Thus the blanking level power is stabilised for changes in system gain. This corrected IF output is then passed to the mixer for which the local oscillator is 38.9 MHz higher than the vision carrier frequency.

The output vision signal, now at UHF, is filtered to remove the unwanted mixing products and then amplified to a level of 1.5 watts by linear amplifiers. The output filter reduces spurious outputs from the local oscillator to a very low level.

Sound

The audio signal is fed into a 600 ohm balanced input and frequency modulation is carried out by imposing this audio signal across a Varicap diode which forms part of the LC circuit for a 32.9 MHz oscillator. The audio signal is predistorted to compensate for the non-linear characteristic of the Varicap diode.

Automatic frequency control (AFC) of the oscillator centre frequency is achieved by varying the potential on a second Varicap diode. The AFC control voltage is derived by sequentially comparing the output of the modulator with two oscillators running at frequencies 500 kHz higher and lower than the sound IF. Using a pulse counting technique two sequential error voltages are derived. These produce a square wave with a peak to peak amplitude proportional to the frequency error of the LC oscillator. After cancellation of audio information, the square wave is switched (alternatively) to the two inputs of a differential amplifier, the DC output of which is fed to the AFC Varicap diode.

An audio monitor and peak reading deviation meter are provided. The output of the FM unit is filtered to remove harmonics before being frequency converted to UHF and amplified in a similar manner to the vision signal.

The output from a temperature-stabilised, crystal-controlled oscillator is amplified to a level in excess of 5 watts before driving a step recovery diode. The eighth harmonic is filtered off and split between the sound and vision mixers as shown in Fig.4.

Reserve Transmitter Drive

In the earlier reserve transmitters, where common sound and vision amplification is employed in the klystron amplifier, the sound and vision signals are combined in the correct ratio at the output of the drive transmitter. The combined signal is then fed to the klystron amplifier which is driven to a power of 2.2 kW peak sync at the output of the transmitter.

Intermodulation products between the sound, vision and colour subcarriers are acceptably low at 2.2 kW. Out-of-band intermodulation products at $f_v - 6$ MHz and $f_v + 12$ MHz are reduced by approximately 20 dB by means of resonators in the output feeder. The output is then fed to the RF change-over switch.

In the later reserve transmitters, see Fig.5, a system of correction is employed permitting the klystron to be driven to an output of 4 kW peak sync. This correction is achieved by combining the sound and vision IF signals immediately before the differential gain correctors. These operate on the combined signals and, when correcting for the klystron, produce intermodulation products in antiphase with those produced in the klystron. This technique enables the klystron to be driven to 4 kW rather than 2.2 kW for the same level of IPs.

Owing to the bandpass nature of the first three klystron cavities and the fact that the majority of the intermodulation occurs in the output cavity, it is not possible to correct out-of-band intermodulation products. Since any out-of-band correction signals from the drive are eliminated by the first three cavities it is necessary to reduce out-of-band radiation by filtering the output of the klystron. This is dealt with by means of a special filter, described later.

Switching Frame

The switching frame contains the sound/vision combining unit for the main transmitter, band-pass filter for the 4 kW reserve transmitter, aerial splitter, RF change-over switch, and 'U' links for bypassing the RF switch for maintenance purposes. The test load is mounted adjacent to the frame. The combining unit for the main transmitter consists of two diplexers and four resonators in a ring circuit. Vision frequencies are split between the two arms of the ring by the first diplexer and are then combined in the second diplexer before being delivered to the aerial. Output from the sound transmitter enters the second diplexer and is split between the two arms of the ring in the opposite direction to the vision signal. Resonators short-circuit the lines at the sound output frequency and reflect

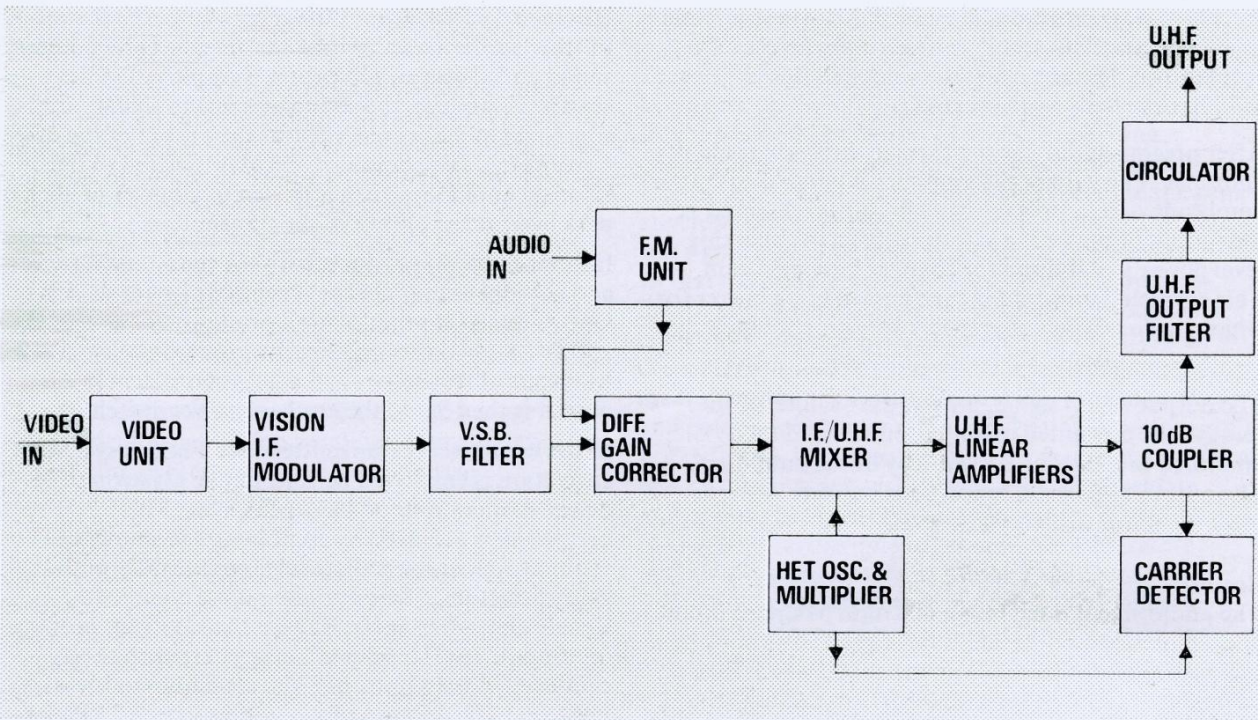


Fig.5. Block diagram of drive system used in the later reserve transmitters permitting the klystron to be driven to an output of 4 kW peak sync. rather than the 2.2 kW of earlier units. Correction is achieved by combining sound and vision IF signals immediately before the differential gain correctors.

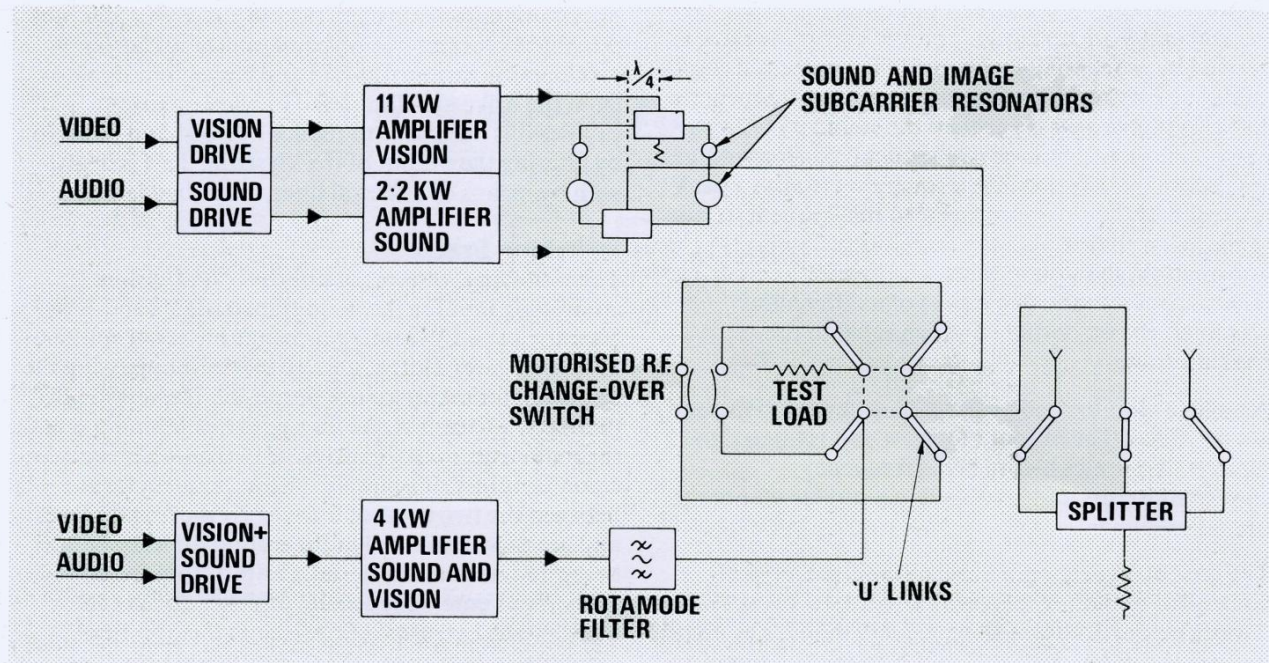


Fig.6. The main/reserve system used with this series of UHF main stations.

power at this frequency back to the second diplexer in such a phase that it is also delivered to the aerial. The unwanted mirror image component of the colour subcarrier in the vision signal is reflected by two further resonators and absorbed in a balancing load.

The filtering of the reserve transmitter is achieved by a Rotamode bandpass filter. The Rotamode* filter² is a four port device which acts as a directional coupler having a coupling factor dependent upon the characteristic of the cavity resonator into which the input and output lines are coupled. Off resonance, the coupling between input and output is minimal whilst at resonance the coupling is high. A sharp bandpass filter is derived by using several cavities in cascade.

Test Load

A vapour-cooled test load is used which can dissipate high power without the need for a circulating pump or any rotating machinery. Power is radiated into a tank of water which acts as a lossy dielectric. At the transmitter power concerned, the water in the tank would take several hours to boil; should it do so, the steam is vented directly outside. The test load system requires infrequent topping up since boiling rarely occurs.

Summary

The IBA already has 15 of these stations in service. The objectives of improved reliability, less maintenance and lower capital cost have been achieved in practice. A further contract for this type of station has been placed, to bring the total to 22, thus completing the high-power UHF main station construction programme.

Acknowledgement

The transmitters described in this section are manufactured by Marconi Communication Systems Ltd.

References

1. R W Leslie, 'Multiplex System for Standby Operation of UHF Television Transmitters'. *BBC Engineering News* No. 85, January 1971.
2. R Hutchinson, 'The Rotamode Combining Filter'. *Sound and Vision Broadcasting*, 14, No. 2, Summer 1973.

* Patent applied for by The Marconi Company

An All-solid-state 10-watt UHF Transposer Equipment

Synopsis

Despite the rapid change to solid state techniques in television during the 1960s, the difficulty of producing transistors able to provide more than just a very few watts of UHF output has meant that thermionic devices continued to be needed in the output amplifiers of television transmitters. But as the building programme reached the stage where it was necessary to plan the large number of low-power local

relays it became possible to think in terms of all-solid-state stations. This would make possible important changes in other aspects of the stations – particularly in buildings and maintenance. It resulted in the development of a range of IBA stations which use 10-watt (ERP up to about 150-watts) modular all-solid-state transposers in conjunction with pre-fabricated container buildings.

The first of these stations was opened in June 1974.

In November 1970, an IBA Working Party was set up to consider future requirements and designs for low power UHF relay stations in the power range of 2–50 watts. This concluded that it would be inappropriate to apply the same design philosophy that had been established for higher power relay stations since this would be wasteful of technical and financial resources.

Clearly, there were various inter-dependent considerations. If, for instance, the equipment design was such that on-site maintenance was necessary, then the building would have to be large enough to set up the test equipment. The maintenance team would be spending several hours on site and therefore additional facilities would be required, such as a toilet and a workbench. It would also be necessary to drive the maintenance vehicle right up to the station to off-load the test equipment; so reasonable access roads would have to be built to all sites, some of which are in mountainous and remote situations. This was already known to be impractical in some cases: an important initial assumption was made that it would be possible to specify equipment where on-site maintenance could be restricted to module or sub-assembly replacement.

Building

Since the equipment would be repaired by module exchange, the maintenance staff need not spend more than an hour on site so toilets could be dispensed with. Furthermore, as no test equipment would be

necessary, the building need be of only sufficient size to accommodate the transmitting equipment, with the barest minimum of additional space. With the close co-operation of the BBC, it was agreed to accommodate all transmitting equipment for both the BBC and the IBA in a common area, thus reducing the size of the building even further. A floor area of about 3 m by 2.5 m was finally agreed. Such a size of building lends itself to prefabrication and a fuller discussion is included in the section on transmitting station buildings.

Access Road

Similarly, if the heaviest replacement module plus carrying case need not exceed, say, 16 kg, then it would be feasible for the maintenance team to leave the vehicle at a convenient point and carry the modules to site. This would make it unnecessary to provide full vehicular access if the station was located in difficult terrain.

Equipment Design

From the above considerations a number of constraints were placed on the equipment:

1. It must be of modular construction and the weight of the heaviest replacement module should not exceed 16 kg.
2. The number of frequency-conscious active modules should be kept to a minimum and these should be capable of being retuned at a maintenance base to cover Bands IV and V.

3. It should be possible to align fully any module at a base maintenance area so that when refitted, the equipment still meets its specification, in every way.
4. The equipment should contain sufficient built-in metering to identify and locate (to within a particular module) any failures without the use of external test equipment.
5. Additionally, and perhaps most important of all, the equipment must be highly reliable and contain sufficient redundancy to allow for at least one fault before complete loss of service. If this could be achieved, then it would not be necessary to provide standby equipment, particularly in view of the lower population coverage of this type of station. This would also result in a considerable reduction of the station cost. To achieve this reliability infers the use of all-solid-state equipment. The Working Party predicted that 2 W solid-state-equipment would be available by 1971, 10 W by 1973 and 50 W by 1975/6.

Fortunately, the IBA had virtually no requirements for 2 or 10 W equipment until 1974, and since thermionic amplifiers had proved adequate for power levels of 50 W and above, attention could be concentrated on the design of all-solid-state equipment to the 10 W power level.

If common vision and sound amplification is used, the output power capability of a linear amplifier normally has to be reduced by about 7 dB to achieve the necessary linearity. The possibility of separate vision and sound amplification was therefore investigated initially, but the problems of designing suitable separating and combining networks with the necessary group delay characteristics appeared unduly complex. Fortunately, semiconductor devices having the required characteristics for use as UHF linear power amplifiers became available as predicted, and made possible combined sound and vision amplification. Investigations were made into the two basic transposer designs: (a) Direct Conversion; and (b) Double Conversion.

(a) DIRECT CONVERSION

It is possible to design transposer equipment which uses only one mixer to frequency change directly from one UHF channel to another. The local oscillator frequency is then the transposition frequency. However it is possible for, say, the second harmonic of the local oscillator frequency to lie within either the received or transmitted channel.

Since it is difficult to achieve sufficiently high spectral

purity of the local oscillator to ensure that harmonics do not occur, this system is prone to spurious emissions. There are other harmonic combinations which can give rise to spurious signals which means that there will be 'forbidden channel' combinations which cannot be used. In view of these limitations it was decided not to use this type of design.

(b) DOUBLE CONVERSION

The conventional design of transposer employs double conversion. In this case the first local oscillator converts the incoming UHF frequency to an intermediate frequency normally between 30–40 MHz. This signal is amplified and filtered at IF to a level where it can be applied to a second mixer for conversion to the UHF output frequency. UHF linear amplifiers can then be employed to raise the power level as required.

In the UK, in order to achieve maximum utilisation of the frequencies available, positive, zero, or negative frequency offsets are employed.

In view of the requirement for a modular design, a formidable problem arises in the generation of all the local oscillator frequencies with the required stability and spectral purity. There are two basic solutions:

1. Synthesizers; 2. Crystal Oscillators.

1. SYNTHESIZERS

Although it would be feasible to construct a synthesizer locked to a precision oscillator at line frequency or sub-carrier frequency to generate each frequency and offset, the cost and complexity involved would not make this an attractive solution; further the large number of components would inevitably affect reliability.

A simpler form of synthesizer is a crystal-oscillator/multiplier based on a nominal 8 MHz crystal, used to drive a step recovery diode to produce a comb of frequencies at 8 MHz intervals. As the UHF channels are spaced by 8 MHz, a filter may be used to select the harmonic required. It should be noted that to achieve positive and negative offsets the basic oscillator frequency has to be offset slightly to achieve the final frequency.

Although this approach has been used successfully in some earlier equipments, it is not really compatible with modular maintenance since the maintenance team would have to carry a frequency counter.

2. CRYSTAL OSCILLATORS

The conventional method of generating the required UHF local oscillator frequency is by means of a crystal

oscillator operating in the 30–70 MHz region, followed by frequency multipliers. Each crystal is unique to the channel and offset required.

Fixed frequency filters can be employed to ensure that the spectral purity of the carrier is sufficiently high. By careful design the need for external test equipment for alignment can be eliminated, as will be seen later.

Equipment Specification

Resulting from the above considerations the following technical specification was drawn up and various manufacturers were invited to tender for the equipment.

Parameter	Acceptance Limit	Remarks
Intermodulation	– 52 dB	Standard 3 tone test Unwanted vision on sound
Cross modulation	7%	
Noise figure	9 dB for input level > 3 mV 6.5 dB when low noise preamp fitted	Peak sync level Ref 2 mV During any one month period
Input signal range	0.5 mV to 4 mV	
AGC range	– 12 dB to + 6 dB	
Frequency stability	± 500 Hz	
Amplitude frequency response	± 0.5 dB – 0.5 MHz to 5.5 MHz	10 step staircase
Non linearity	8%	
Diff. gain	8%	Ref black level Change in black level
Diff. phase	± 3°	
Sync crushing	± 3%	p – p rel picture Unweighted 1 mV input
Group delay	± 40 ns	
LF Noise	– 50 dB	
S/N ratio	43 dB	
Pulse and bar	2% K	10 Hz – 2 kHz square wave Unweighted Weighted
LF Response	1% tilt	
FM Noise	– 56 dB – 66 dB – 60 dB	Anticipated target
Spurious outputs	20 dB return loss	
Input impedance	10,000 hrs	
MTBF		

Equipment Purchased

A number of equipment designs were considered and an order was placed for the 10 W equipment shown in Fig.1.

This consists of two racks, the lower being the low power transposer, and the upper, the 10 W solid-state amplifier. The block diagram of each rack is shown in Fig.2 and 3 respectively. Each rack consists of drawers and each drawer is built up from a number of modules. A typical drawer is the *1st Converter* shown in Fig.4, and it can be seen that it consists of inter-connected active and passive modules. Each module

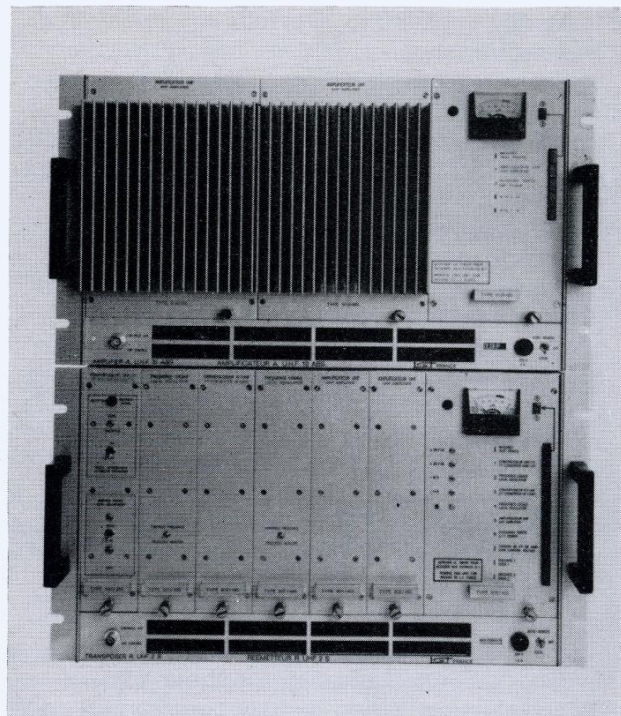


Fig.1. The 10-watt all-solid-state transposer of the type being installed in the first batch of the type 10S relay stations. The first of these equipments went into service at Luton in June 1974. Typically effective radiated power is of the order of 100 to 150 watts, although in a few stations this may be as low as 20 watts. The upper rack is the 10-watt amplifier and the lower rack the transposer. Each rack consists of a number of 'drawers' and each drawer is built up from a number of modules which can be disconnected and removed independently. The active modules are broadband and cover Band IV or V or both without readjustment and any faulty module can be diagnosed readily by means of the front panel meters.

can be disconnected and removed independently. Each active module is broadband and covers Bands IV and V without readjustment. A faulty module can be diagnosed by means of a lead connected to the front panel meter. The drawer contains seven modules:

- (1) UHF Input Filter; (2) Broadband Low-noise UHF preamplifier; (3) Image Noise Filter; (4) Diode Mixer; (5) IF Filter; (6) IF Amplifier; and (7) Auto switch on and AGC module.

The next drawer is the *Local Oscillator* and both the first and second Local Oscillators are identical. This consists of a crystal oscillator in a constant temperature oven, a transistor multiplier unit, a varactor tripler, and four sets of fixed frequency filters. Although the active modules are in this case tuned for each channel this can be carried out by means of the test points in

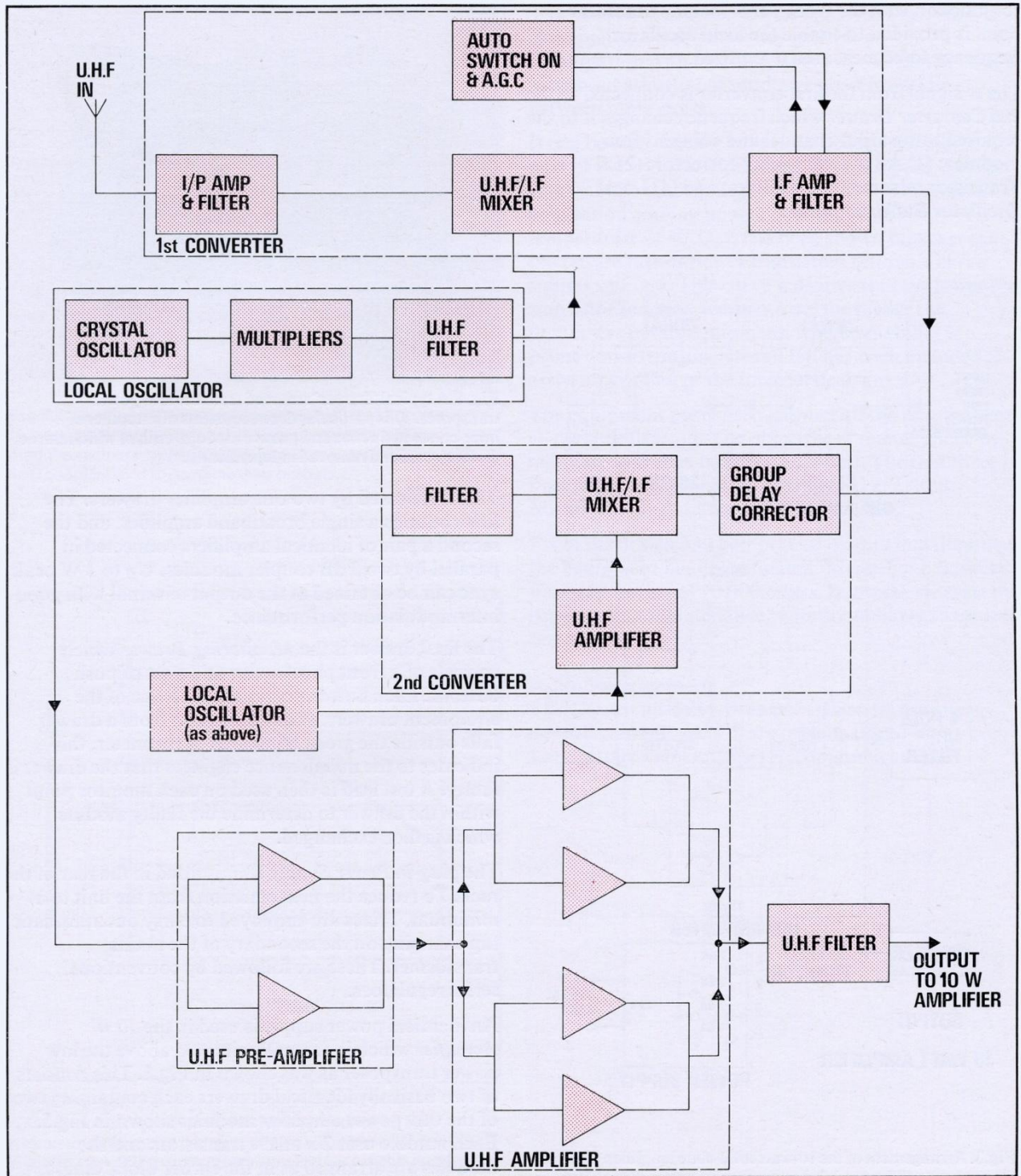


Fig.2. Block diagram of the low-power solid-state transposer which provides up to 2-watts peak sync.

conjunction with the front panel meter. A monitor point is provided to enable the local oscillator frequency to be measured if required.

The IF signal from the first converter is connected to the *2nd Converter Drawer* which frequency changes it to the required UHF output channel and contains four modules: (1) An IF group delay corrector; (2) A Transistor mixer; (3) UHF Filters; and (4) Local Oscillator Buffer amplifier.

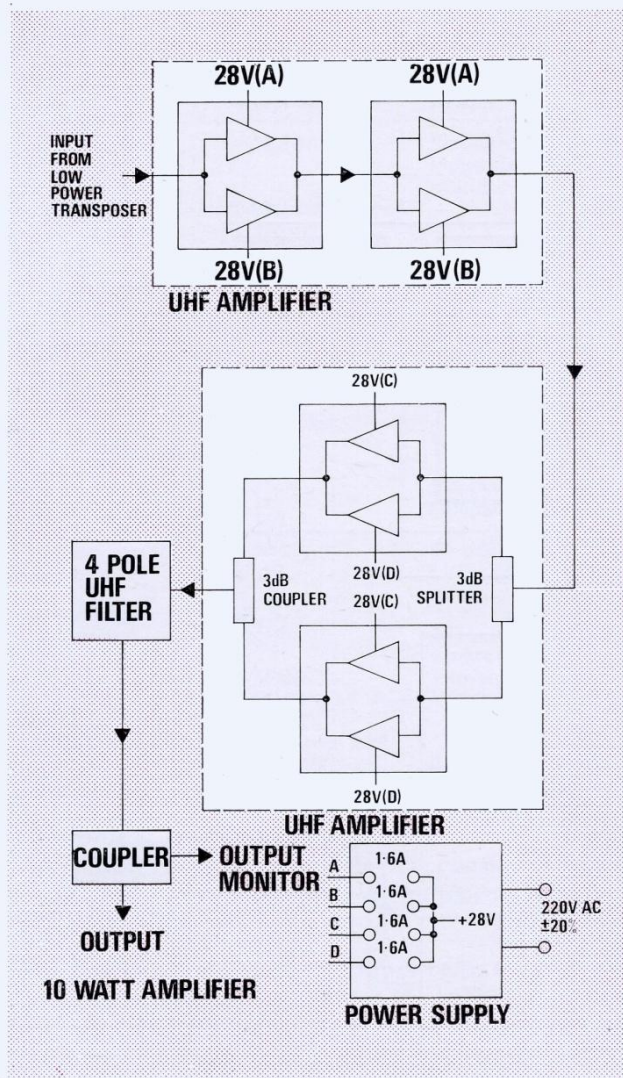


Fig.3. Arrangement of the 10-watt solid-state amplifier. Each of the power amplifier modules uses two BLX98 transistors with a 3 dB coupler which combines the outputs of the modules with low loss and which operates over Bands IV or V without adjustment.

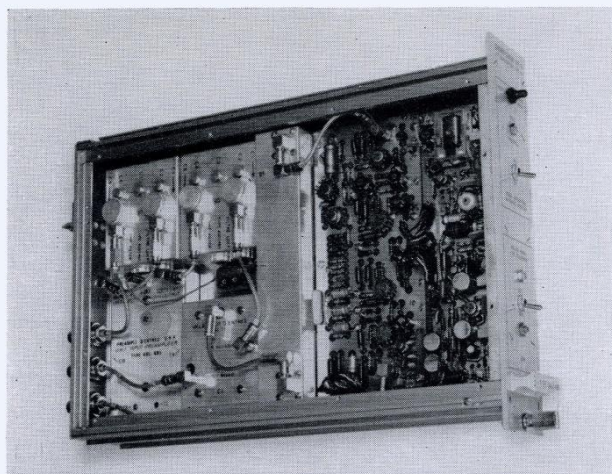


Fig.4. A typical 'drawer' removed from the low-power transposer. This particular drawer consists of a number of inter-connected active and passive modules each of which can be disconnected and removed independently.

This is followed by two UHF amplifier drawers. The first contains a single broadband amplifier, and the second a pair of identical amplifiers connected in parallel by two 3 dB coupler modules. Up to 2 W peak sync can be obtained at the output terminal with good intermodulation performance.

The final drawer is the *Monitoring Drawer* which consists of a front panel meter and a set of push buttons. Each button corresponds to one of the equipment drawers. If the indication from a drawer falls outside the green band area of the meter, this indicates to the maintenance engineer that the drawer is faulty. A test lead is then used on each monitor point within the drawer to determine the faulty module which is then exchanged.

The plug-in *Power Supply Unit* is fitted in the rear of the rack. To reduce the heat emission from the unit to a minimum, Triacs are employed to carry out automatic tap changing on the secondary of the mains transformer. These are followed by conventional series regulators.

An identical power supply is used in the *10 W Amplifier* which is normally situated above the low power transposer as was shown in Fig.1. This consists of two basically identical drawers each containing two of the UHF power amplifier modules shown in Fig.5. Each module uses $2 \times \text{BLX98}$ transistors and the modules are arranged as in the earlier block diagram, Fig.3. 3 dB couplers are used to combine the outputs of the modules.

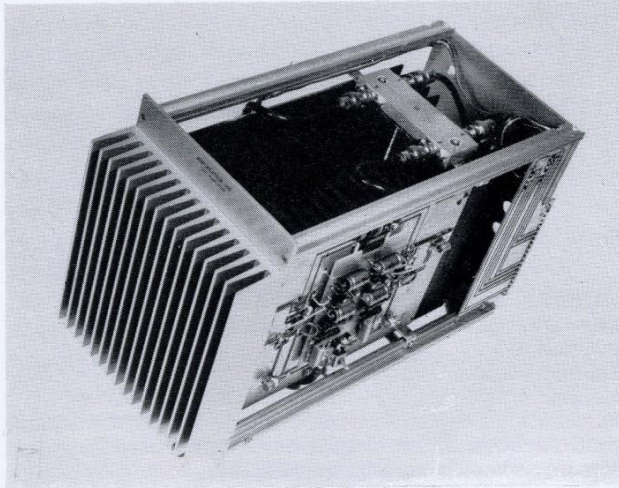


Fig.5. One of the two identical drawers which make up the 10-watt power amplifier. Each drawer contains two of the modules each of which incorporates two BLX98 transistors with 3 dB couplers used to combine their outputs.

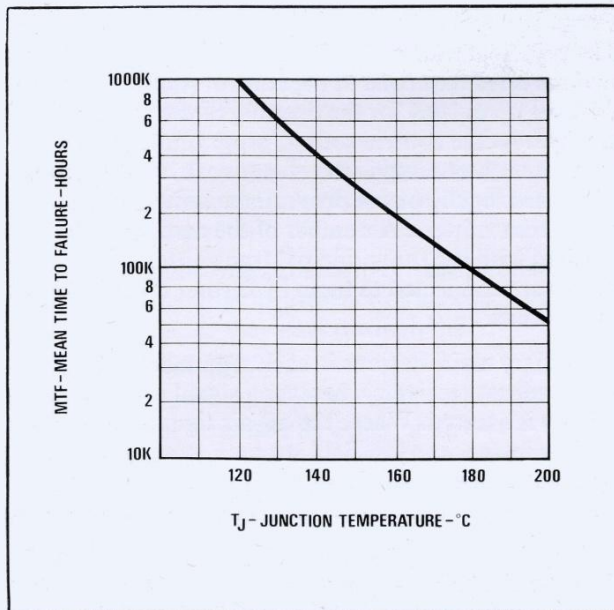


Fig.6. The use of substantial heat sinks means that the equipment can rely on natural convection cooling up to a maximum ambient temperature of 40°C. The importance of achieving low transistor temperatures is shown in this graph which indicates how dramatically UHF power transistor reliability increases with low junction temperatures - from about 100,000 hours at 180°C to one-million hours at 120°C.

The major advantages of 3 dB couplers when used in this application are that they provide power combination with low loss; operate over Bands IV and V without adjustment; and give good isolation between input ports.

It can be seen that the heat sinks occupy the major part of the volume of this rack. The design of the heat sinks is such that the equipment can rely on natural convection cooling up to a maximum ambient temperature of 40°C. It has been shown however that the failure rate of power transistors follows a curve similar to Fig.6. This curve indicates that the lower the transistor junction temperature, the higher the reliability; in this equipment, where reliability is a prime consideration, a small fan has been included to assist air cooling of the internal heat sinks.

The equipment purchased has met all the requirements of the specification. The objective of maintenance by modular exchange has been achieved. The first three of these equipments became operational at Luton, Marlborough and Morpeth in June 1974.

From the design and component quality and quantity the equipment has an estimated 'Mean Time Between Failures' (MTBF) of 10,000 hours. In practical terms this suggests that maintenance visits are unlikely to exceed one a year.

Acknowledgement

The 10-watt all-solid-state transposer-transmitters described in this section are manufactured by Laboratoire Général des Télécommunications.

Control Systems for Unattended Stations

Synopsis

When the IBA UHF transmitter network was first planned, the decision was taken that from the outset all stations would be designed for unattended automatic operation. This decision followed earlier work by the IBA in the successful operation of unattended VHF relay stations of up to 10 kW ERP. But the new network involved radiated powers of up to 100 times more than any of the unattended VHF stations. Automatic operation must be supplemented by control and supervisory

systems and must be based on a careful appraisal of how the whole transmission system is organised, monitored and maintained.

This section describes some of the telemetry and automatic monitoring techniques being used and installed at IBA transmitting stations. A description is given of a monitoring control room and some suggestions are made as to the direction which future improvements may take.

The IBA transmitter network is designed for unattended operation, depending primarily on automatic control to maintain the continuity and quality of the service. For this reason virtually all the transmission equipment is duplicated at each station. This includes the transmitters, the SHF link equipment or re-broadcast receivers, video and audio distribution amplifiers and power supplies. Control systems are provided wherever practicable to handle daily switching operations and the selection of reserve equipment.

The aim here is to show how an understanding of the transmission system and the organisation of the maintenance teams is essential before a useful control system can be engineered for a broadcasting organisation.

IBA stations are broadly categorised as main and relay stations, depending upon whether they are built around transmitters or transposers.

Transmission Equipment

Transmitters may be arranged as parallel amplifiers fed from common or individual modulators, or as main and reserve equipment. The reserve equipment may have equal or lower power than the main transmitter.

Parallel transmitters require simultaneous video and audio inputs from distribution amplifiers, and it is convenient to use similar distribution amplifiers for main and reserve arrangements.

Transposer equipment may likewise be operated in parallel, or as main and reserve low power

transposers with parallel amplifiers or as quite separate main and reserve chains.

Thus there is a variety of transmission equipment configurations calling for different control arrangements.

Programme Paths

The principal transmitter in each of the ITV programme regions is fed from one of the control rooms which were set up in 1969 for the opening of the colour service¹. At the control rooms, programme signals from the companies via the PO network, or test signals generated locally out of programme hours, are routed to the transmitters. A number of the control rooms are co-sited with the UHF principal transmitters, while others are connected to them by further rented PO lines or SHF links.

Subsidiary main stations in each region are fed by re-broadcast receivers wherever a signal of adequate quality is assured. Where the off-air signal is unusable, due for instance to low field strength, co-channel or adjacent channel interference, a line or link is rented from the PO. If these are not available then IBA SHF links are used.

Over particularly long or difficult paths, for example, passing over the sea or tidal estuaries, diversity reception is used, with two aerials at different heights, each feeding a receiver. The less noisy output at any instant is selected for transmission by a noise diversity switch of IBA design².

Thus, in addition to several transmitter configurations,

there is a variety of programme input equipment (PIE) to be controlled, depending upon the method used to convey the programme to the transmitting stations. Relay stations are somewhat simpler since demodulation and re-modulation are not involved.

Where re-broadcast reception is used, these stations are clearly dependent upon other stations for their programme, the latter becoming correspondingly more important in the network of transmitters. This can readily be understood in terms of effective population coverage. One station may be intended to cover a population of 10 million people. Another fed from it may be intended for a further 1 million. Thus the effective population coverage of the principal or 'crucial' main station would be 11 million people. In general the IBA's crucial transmitters, where continuity of service is paramount, have paralleled equipment but non-crucial stations have main and reserve transmitters, where the short break in transmission on change-over can be tolerated.

Automatic Control

The controls necessary at a transmitting station fall into two main groups: (1) Routine; (2) Remedial.

Routine controls occur during normal operations and include switching the station on and off each day to minimise power consumption and to prolong the useful lives of thermionic (and some solid state) devices.

Remedial controls are necessary when a fault has occurred but where the substitution of duplicated equipment will maintain the service.

The need for control action is established at unattended stations by detecting the presence or absence of signals in various forms as they pass through the transmission equipment.

Programme input equipment is never turned off so the video input can be sensed by a pair of field synchronising pulse detectors, one on the output of each line, link or re-broadcast receiver. The presence of pulses at one output is sufficient to switch on a station, but both must be absent before a shut-down sequence is started. The audio input from PO lines is sensed by programme detectors. At each 'crucial' transmitter a low level super-audio pilot tone is injected in the sound channel. At re-broadcast stations this can be detected separately and used to prove the continuity of the sound chain.

Within the transmitters, presence of unmodulated RF is used to prove that the low level drives are working;

at the outputs, carrier detectors fed from feeder probes show that the high level signals are also present. The vision carrier detectors can be adjusted to respond to the presence of synchronising pulses, showing that modulation is taking place.

The outputs of all these detectors are treated as logic signals and used to change-over the appropriate part of the chain after suitable delays which minimise spurious action. Such change-overs can take place automatically and each station is conceived as a self-contained entity, not needing outside intervention to maintain a service after one fault. Even some double fault conditions will not interrupt the service, but the cost of allowing for all possible combinations of double faults is not thought to be justifiable.

Automatic Monitoring Equipment

At the opening of the colour service it was possible to receive at the control centres off-air pictures suitable for monitoring from nearly all the transmitters. Thus subjective faults in the radiated pictures, which were not detectable by the simple devices mentioned above, could be seen by control room staff who could if necessary initiate corrective action by a mobile maintenance team (MMT).

As the network grows, off-air monitoring becomes less viable; the number of possible interfering sources is increasing and the new stations are usually of lower power. Fortunately, automatic monitoring equipment (AME) has been developed (ref. 3,4,5) which gives a useful measure of the performance of a station in terms of distortions of inserted test lines (ref.6,7). The test line is inserted at each control room and suffers a cumulative degradation as it is distributed through the transmitter networks. By arranging for an AME to compare an incoming signal with a demodulated version of the transmitted signal, it is possible to decide if the fault lies in one of a pair of receivers, in one of a pair of parallel transmitters, in the single main transmitter, or outside the station altogether. If the degradation exceeds pre-selected limits (corresponding to subjectively unacceptable pictures), an AME can initiate a suitable change-over. Again, control action is contained within the station itself and takes place automatically, complying with the fundamental concept.

As confidence grows in this system, more stations are being equipped with AMEs and eventually it may be possible to abandon conventional off-air transmitter

monitoring. Much work remains to be done, however, on the choice of limits, both singly and in combination. The 'double fault' problem is compounded when several parameters may be distorted simultaneously and an attempt is made to relate such a situation to the six-point scale of subjective picture degradation.

Remote Supervision and Control

Although stress has been laid on the automatic operation of unattended stations, supervisory equipment is also essential to the maintenance operation. It is necessary to know the state and relative importance of all the transmitters in an area so that when faults occur, they may be allotted degrees of priority for repair.

For the purposes of allocating supervisory equipment, stations are categorised in order of effective population served. Nearly all large populations are covered by main stations while the smaller pockets are covered by relay stations. There are the inevitable exceptions; for example a few relay stations cover several hundred thousand people, and there are main stations covering a few tens of thousands; in such cases the main station/relay station distinction overrides the population criteria.

The response time of telemetry systems to a change of state at unattended stations has been chosen as a function of population coverage. Thus 'crucial' stations communicate with control rooms immediately, non-crucial stations within 10 minutes, less important stations within a few hours and so on; the least important stations have no telemetry equipment, reliance being placed on dealers' and viewers' reports.

All main stations are provided with Teledac* remote control equipment and relay stations with Telecode* equipment. The Teledac* system uses a computer-like central processor which can handle many stations simultaneously, but the Telecode* can deal with stations only one at a time.

Rented PO lines are used for crucial stations, but non-crucial stations with Teledac* use the public switched telephone network, as does the Telecode* system.

Reference 8 discusses the need for controls, alarms and indications and may be summarised by saying that controls are needed to override or supplement automatic control, if the latter is inadequate or in fact fails. Indications are needed to show the status of the

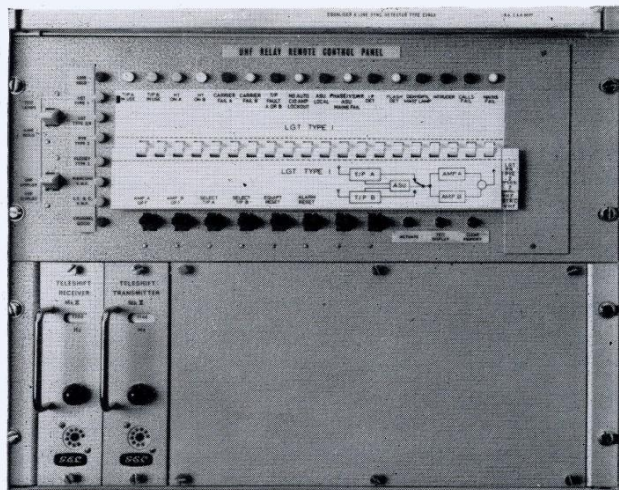


Fig.1. A typical Telecode master installation at a regional colour control centre. In this case the 'book of legends' provides a key to the control keys and lamp indicators for a 1 kW UHF relay. By turning the 'pages' similar keys to other types of VHF and UHF relay installations are immediately available.

transmission (and telemetry) equipment at any time and also to give a clear message to the operator that remote controls have taken effect. Alarms are needed to convey both catastrophic and 'early-warning' information to show that maintenance limits have been passed or to forestall a break in transmission. To some extent the telemetered information is used to decide not only the relative urgency of a fault but also whether engineers, electricians or riggers should attend to it.

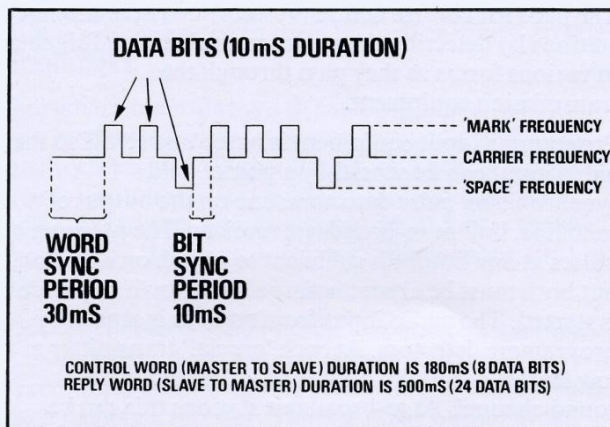


Fig.2. The Telecode word structure is based on a three-state return-to-zero system with successive 'marks' and 'spaces' separated by a 33.3 millisecond carrier burst, providing an effective data bit-rate of 15 bits/second.

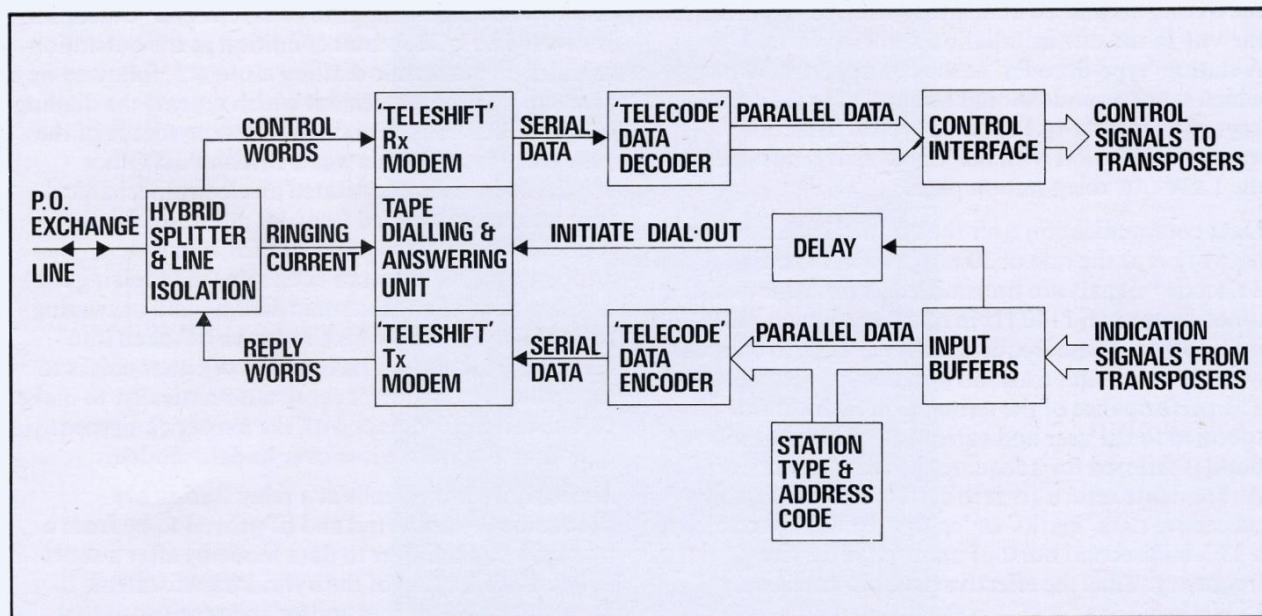


Fig.3. Block diagram of a Telecode outstation installation. A fault condition at the unattended relay station initiates an automatic dialling sequence followed by a recorded announcement (this Post Office requirement is being relaxed and a new electronic dialling and answering unit will be used in future). The hybrid transformer isolates the modem (modulator-demodulator) unit so that data can flow either way without interaction. The system will operate with a line loss of up to 35 dB.

Present telemetry systems in use in IBA are confined to binary or on/off indications and alarms. Although telemetry of analogue quantities may be of interest, these would be of little value without corresponding analogue controls, which so far have not been needed. However, as more use is made of automatic monitoring equipment, the choice of fixed limits in an extended network becomes a difficult one, particularly when some parameters suffer cumulative degradation while others are improved or restored by processing circuits in the transmitters. Eventually therefore, it may be found necessary to telemeter some numerical information in such networks. It is still considered, however, that on-site automatic control is the ideal and that operational dependence on control lines or data links should be avoided so far as possible.

Relay Station Telemetry Equipment

The relay station equipment is described first since it is simpler than that at the main stations, yet forms a convenient introduction to the latter.

The controls and indications from the transposers at a relay station, together with sundry connections to ancillary equipment such as dehydrators, intruder alarms and power failure relays, are grouped together

in an interface unit of IBA design, which presents all the functions to the proprietary Telecode* equipment as standard logic signals. Over the past few years some progress has been made in agreeing standard logic signals with transmitter manufacturers in an attempt to minimise the degree of interfacing between proprietary items of equipment; but there is plenty of scope for more progress in this direction. Free collectors of grounded emitter NPN transistors have been used successfully at the interface but a floating relay contact is a convenient alternative, provided that sufficient attention is paid to ratings, wetting currents and reliability.

A further important function of the interface is to slow down the response of the logic circuits so that noise, transients and other interfering signals do not produce unwanted call-outs. Call-outs also have to be inhibited at normal shut-down and during the warm-up period.

The Telecode* slave is equipped to allow 8 two-state controls to be sent from the control room to a relay station and 24 on/off indications to be received back; 8 of these are reserved for a station type and address code. Where VHF and UHF relay stations are co-sited,

the 8 controls and 24 indications can be switched from the VHF to the UHF installation and vice versa. A station 'type-decoder' at the control room shows which set of legends should be applied to the control keys and lamps. Fig.1 shows a typical Telecode* master installation with the 'book' of legends open at the 1 kW UHF relay station page.

Data communication over the PO switched telephone network is at the rate of 30 bits/sec. and the digital Telecode* signals are transmitted as frequency shifted tones centred on 1140 Hz in one direction and 1380 Hz in the other. These frequencies are chosen to coincide with the minimum transmission loss in the PO network. The performance of the switched network is not specified to the user and varies between connections, but it is tailored for adequate speech transmission. A three state return-to-zero system is used (Fig.2), successive data 'marks' or 'spaces' being separated by a 33.3 millisecond burst of undeviated carrier frequency. Thus the effective data bit-rate is only 15 bits/sec.

A simplified block diagram of a Telecode* outstation is shown in Fig.3. A fault condition at the outstation initiates an automatic dialling sequence, followed by a prerecorded announcement which repeats the dialling information verbally and identifies the source of the call. Until recently this was a British Post Office requirement and necessitated an electromechanical tape unit which needed frequent attention. In our particular case the requirement for spoken announcements has since been relaxed, allowing the development of an electronic dialling and answering unit (Teleconnect*) which is due to be taken into service during 1974. The function of either unit is to set up a call to a control room automatically, to make sure that it is in contact with the master equipment and then to hand the line over to data modems.

Similarly incoming calls at a relay station are automatically answered and (if proved to be from a master) switched over to data modems after a short delay. The function of the hybrid transformer is to isolate the modem transmitter and receiver so that

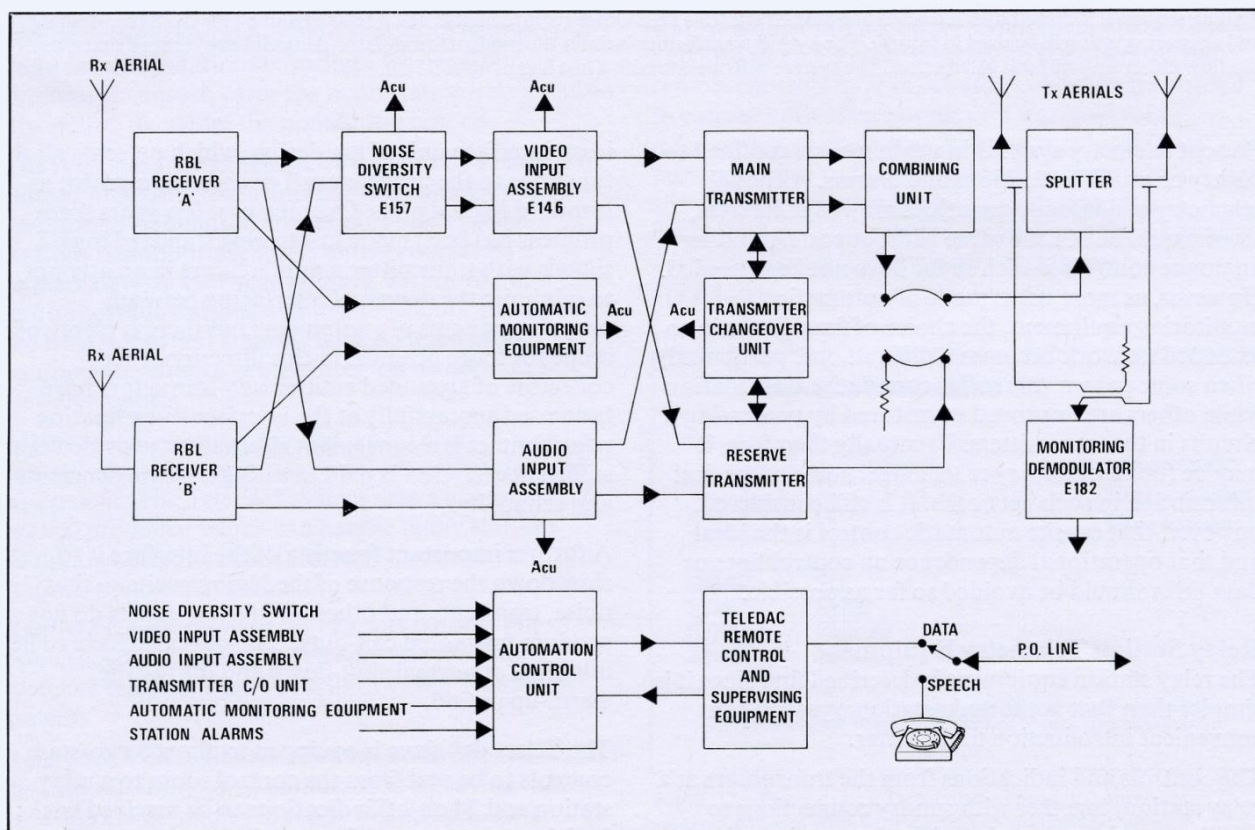


Fig.4. Simplified block diagram of the telemetry system used at a UHF main station.

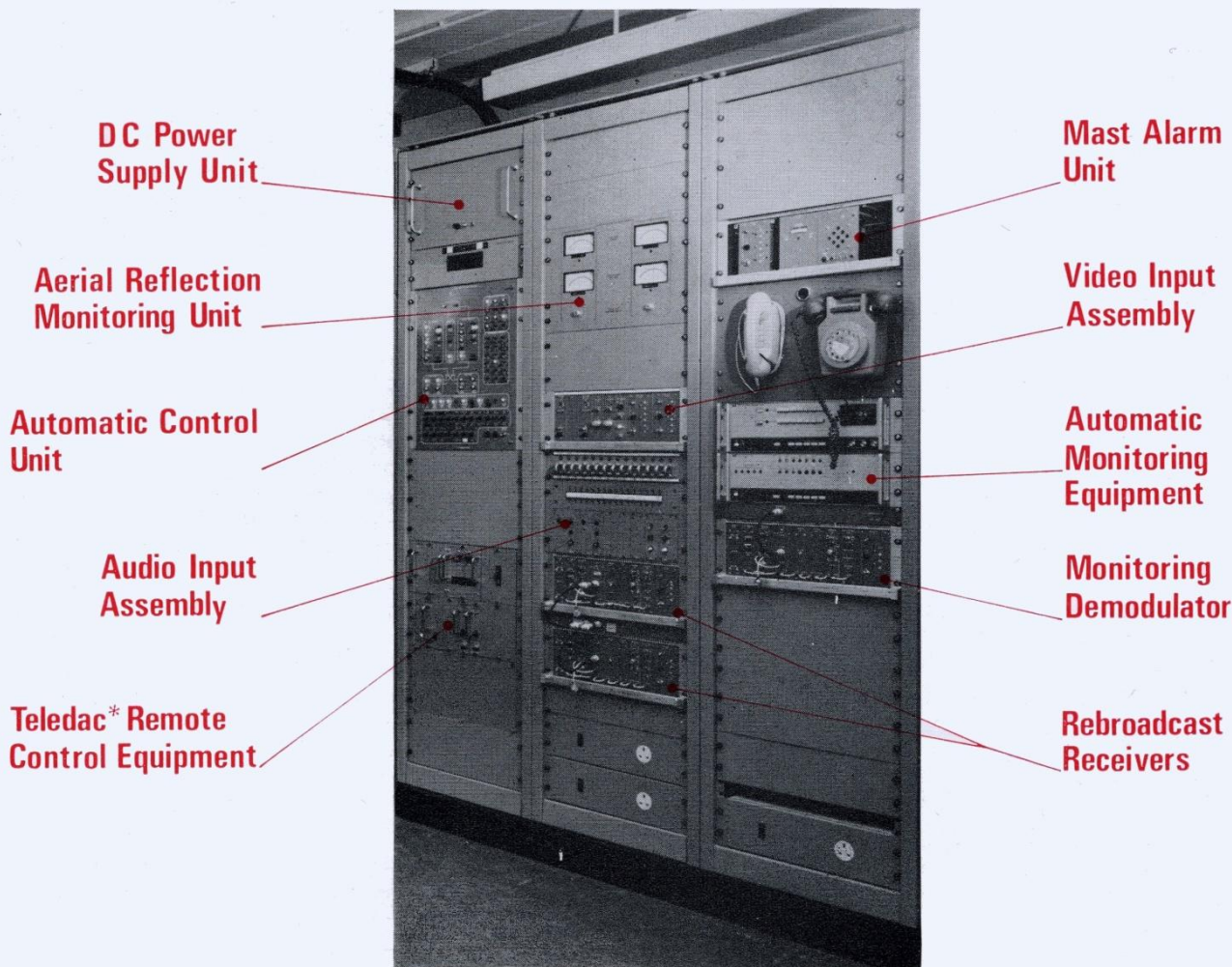


Fig.5. The programme input equipment (PIE) bay at a UHF main station showing how the Teledac telemetry equipment is installed. Since a number of different proprietary equipments have to be combined to form a complete system the special logic interface units are necessarily rather complex. Whereas television engineers have long standardised signal paths (e.g. 1-volt in 75-ohms) the logic connections still vary in level, polarity and sense although progress is gradually being made to standardise logic signals.

data can flow either way without interaction. The isolation attainable is limited by the tolerance of the line impedance, but adequate isolation is normally achieved. The use of different carrier frequencies for send and receive enhances effective isolation.

Transmission in either direction is independent, and at either end the FM (or FSK) signals sent at a level of -9 dBm are demodulated to produce a digital pulse train. The system will operate reliably with a line loss of up to 35 dB. Clock signals derived from the incoming data are shifted bit-by-bit into shift registers and when complete transferred in parallel to a further

store, provided that simple checks have been made. The store lights lamps at the master or feeds a control interface at the slave station, where signals of appropriate voltage level and duration are generated for application to the transposers.

It will be appreciated from Fig.3 that additional circuitry is necessary to multiplex the groups of indications from co-sited UHF and VHF transposers and to decode and route the control messages to the individual transposers, enabling the appropriate set of data output lines.

At present, telemetry calls received at Control Rooms

from relay stations are taken manually, and when a call has been recognised by the operator it is diverted to the master equipment. Once the electronic dialling and answering unit (Teleconnect*) is in service it is intended to automate this function and the need for the coded 'electronic' address of each station becomes apparent. Automatic answering, backed up by storage of incoming information for display when convenient, will relieve control room personnel of unnecessary routine work as the number of relay stations reporting to each control room increases.

Main Station Telemetry Equipment

Basic transmitter change-over controls derived from loss of carrier or low level drive are achieved by a logic unit within the transmitter, but the unit also has to accept instructions from automatic monitoring equipment or directly from a control room via the Teledac* remote control and supervisory equipment.

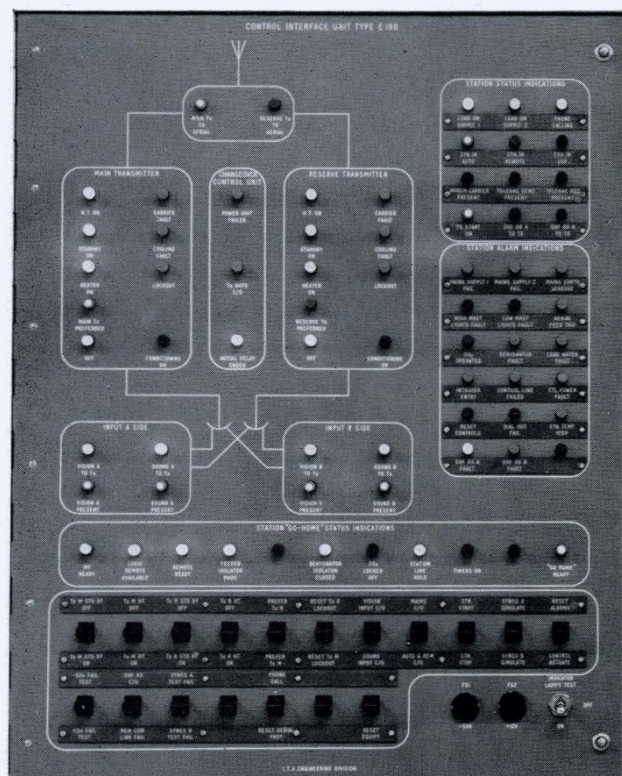


Fig.6. The IBA control interface unit type E188. The station on/off signals are generated in this unit, which is arranged to provide a mimic diagram of the station, repeating all telemetered information. It also carries control keys to simulate remote control for fault-finding and maintenance purposes.

At a main station, many more items of proprietary equipment, perhaps from six different manufacturers, have to be combined to form a complete system and the specialist logic interface which interconnects them becomes fairly complicated. Unlike signal paths which have standard levels and impedances, e.g. 1 volt of video in 75 ohm, logic connections vary in their levels, polarities and senses. As mentioned earlier, some progress is being made in standardising such signals.

Fig.4 is a block diagram showing the relationship of the various items and Fig.5 shows how they are installed at a typical main station. The interface, or automatic control unit, is identified by its IBA type number E188. The station on/off signals are generated in the automatic control unit, which carries a mimic diagram of the station (Fig.6) repeating all the alarms and indications which are telemetered. It also carries a set of control keys whose action simulates remote control for diagnostic fault finding and maintenance purposes. Control signals emerge from the Teledac* in the form of fleeting pulses to earth from free-collector transistors. As far as possible, all controls are actuated as pulses of this form, which therefore have to be simulated for local control.

Fig.7 is a simplified block diagram of the automatic control unit. Modular construction is used which allows the units to be equipped with circuit cards appropriate to the variations at each station.

To accord with the policy of automatic rather than remote control, the design ensures that, if remote control is not available because of line or slave equipment failure, the system reverts to automatic control. Thus remote control has to be deliberately selected before controls can be executed from a control room.

The Teledac* 'slaves' at main stations are normally equipped to allow 32 controls, 32 alarms and 32 indications; co-sited UHF and VHF stations require twice this number. Small SHF link stations, which are of course as crucial as the stations they feed, are allocated half this number.

Crucial stations are connected to control rooms by rented lines to allow immediate access, and non-crucial stations use the public switched telephone network in the same way as relay stations, using similar dialling and answering units, line isolation and hybrid transformers and modems. On private or subscriber lines, a signalling speed of 50 bits/second is used at carrier frequencies of 1140 and 1380 Hz.

A Teledac* master scans all the outstations on private lines continuously and raises an audible alarm on receipt of a new alarm state. If an outstation calls in on the switched network, the call is answered automatically and the scanning routine is enlarged to take in the additional station. If a remote control signal is sent, the scanning is briefly interrupted to allow a control sub-routine to take place. Outstations each have a unique digital address, and although all are 'listening' to the master, they respond only in turn, one at a time.

Fig.8 is a simplified block diagram of the Teledac* master, showing how the central processor unit works from the program contained in diode matrix cards, which are modified when new slaves are added. Under the control of the processor, data is admitted to internal highways from slaves via line termination units and directed to display stores for fixed key and lamp panels, and an intermediate or 'volatile' store for switchable panels. Each crucial station has its own key

and lamp panel for control and display (Fig.9) but non-crucial stations are only in contact with the master one at a time and where they are of the same type, share a switchable panel.

The data words have a 24-bit structure, shown in Fig.10, made up of a start bit, 16 data bits, 5 parity bits and 2 stop bits. The 5 parity bits are derived from a cyclic error detecting code which gives a very high immunity to transmission interference. Data is far more likely to be rejected than incorrectly transmitted in the presence of data-like interference. Control messages are made doubly secure by arranging for outstations to repeat their instructions for validation before the message is sent actually to carry out or 'actuate' the control.

Synchronisation between master and slave is not achieved by interleaving synchronising pulses as with Telecode*, but by relying upon the accuracy of crystal oscillators of the same frequency at each end. When carrier and a message start bit are received by a slave,

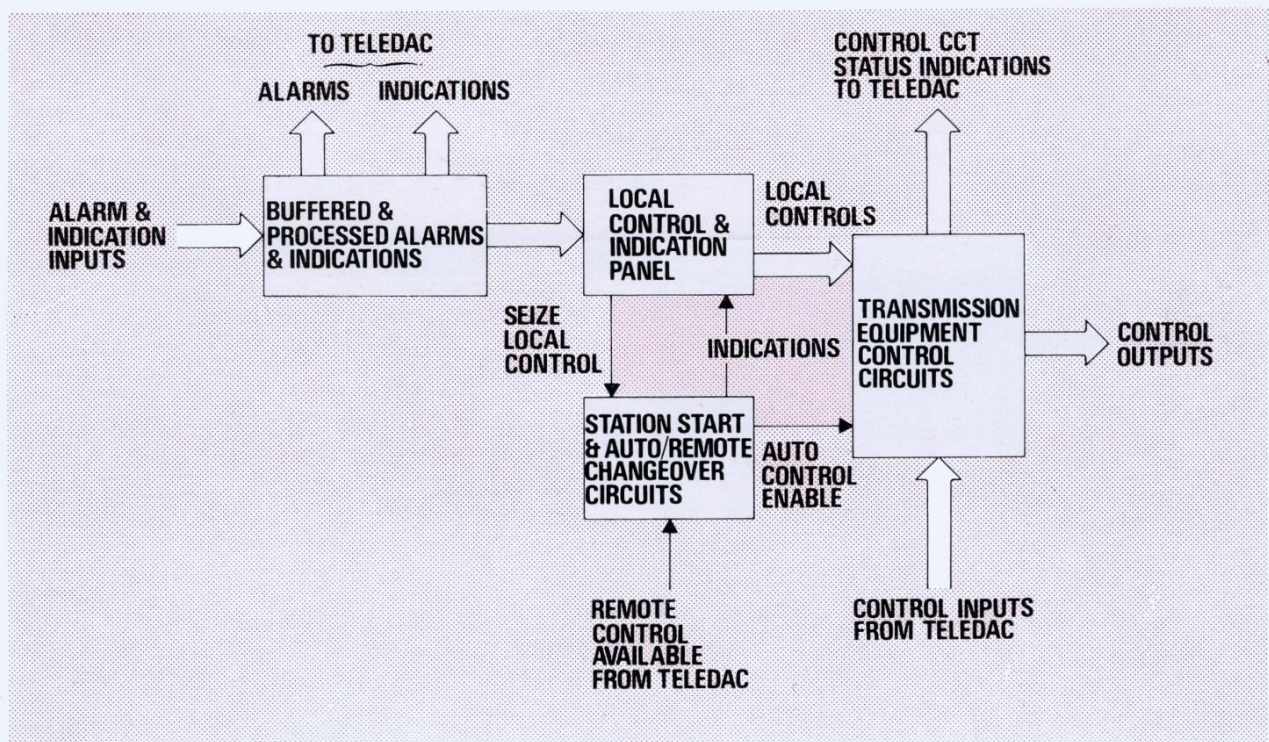


Fig.7. Simplified block diagram of the IBA automatic control unit which forms the interface between the Teledac units. Modular construction allows the units to be equipped with circuit cards for the particular equipment at each outstation. The design ensures that if remote control is not available due to line or slave-equipment failure the system reverts to automatic control. In effect remote control has to be 'seized' before any operational controls can be actuated from the regional control centre.

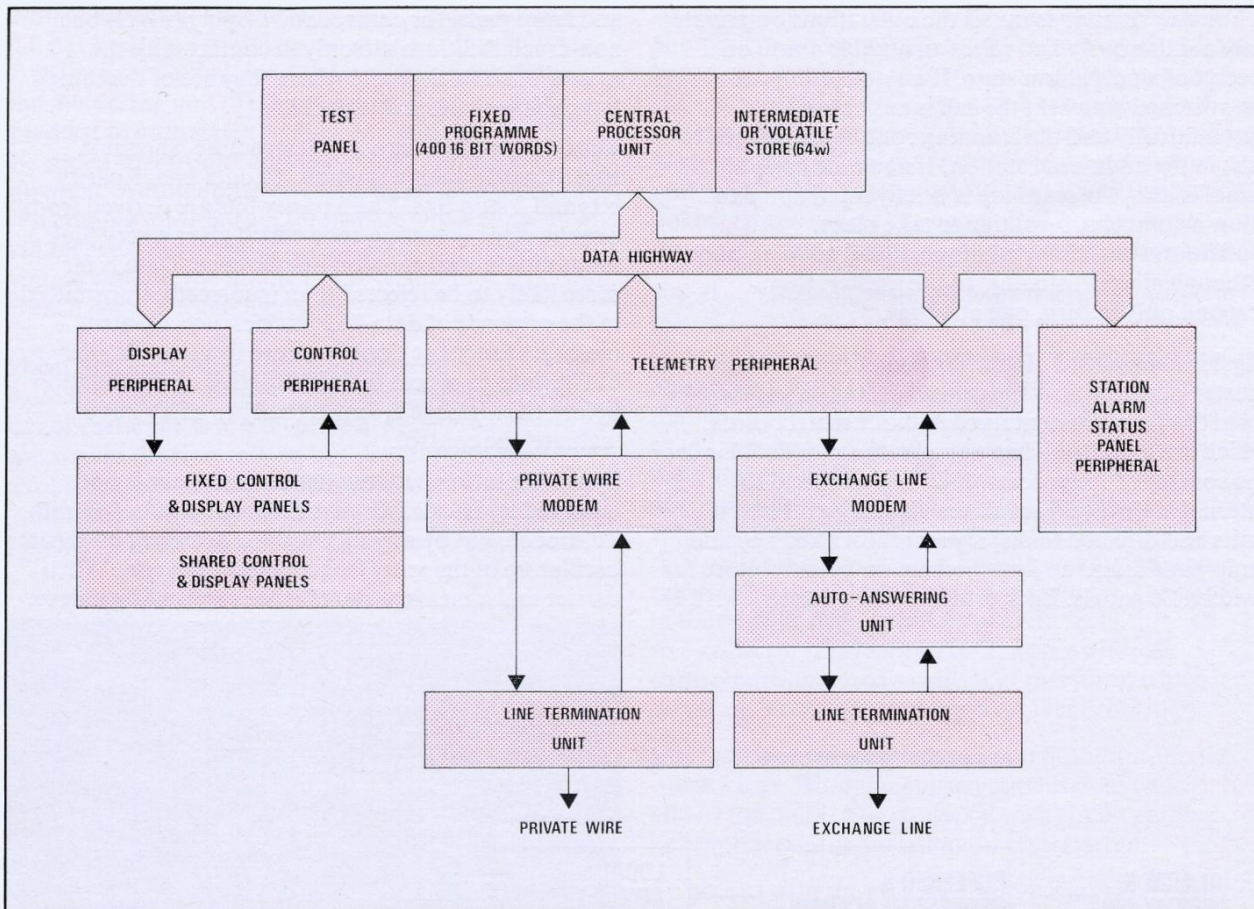
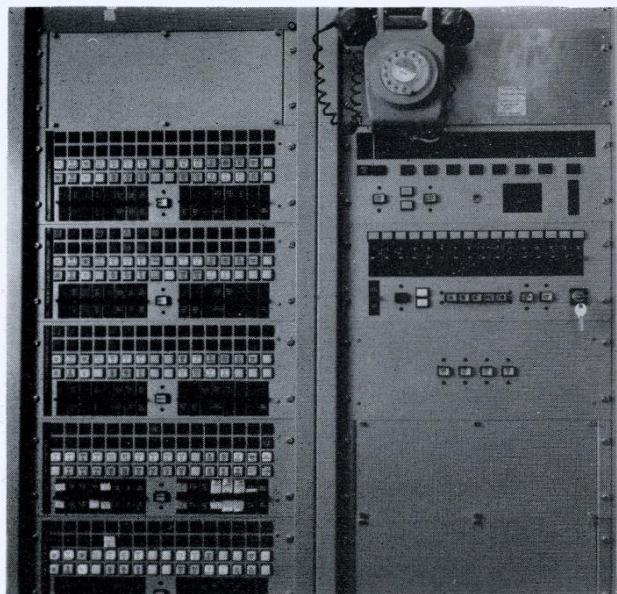


Fig.8. Simplified block diagram of a Teledac master unit showing how the central processor works from the programme contained in diode matrix cards which can be modified when new slave units are added.

a 'sync release' pulse allows a clock oscillator and divider chain to run. This allows the full signalling speed to be exploited for data, rather than half used merely for synchronisation, although it involves the addition of crystals and extra circuitry.

Safeguards built into the program ensure that only one control at a time is accepted by the master for transmission. At the slave, if more than one potential control is sensed at the output simultaneously, all are suppressed.

Fig.9. Banks of Teledac key and lamp panels. Each 'crucial' outstation has its control and display unit but other stations can share a unit by time-multiplexing.



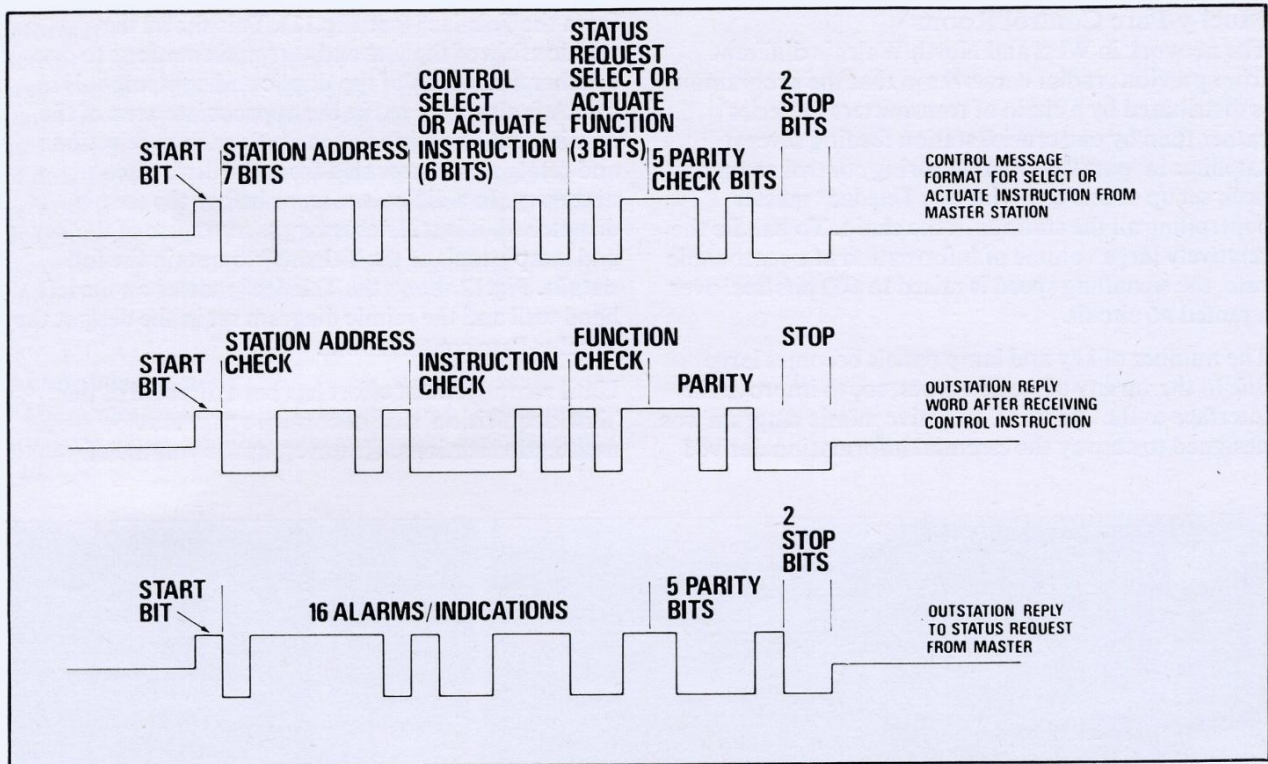


Fig.10. The Teledac word structure. Data words are made up of 24 bits: a 'start' bit, 16 data bits followed by 5 parity bits and two 'stop' bits. The use of 5 parity bits derived from a cyclic error detecting code provides a high degree of immunity to any transmission noise or interference. Control messages are made doubly secure by the outstations repeating instructions for 'validation' before the final control command is given. Synchronisation depends on the use of independent crystal oscillators.

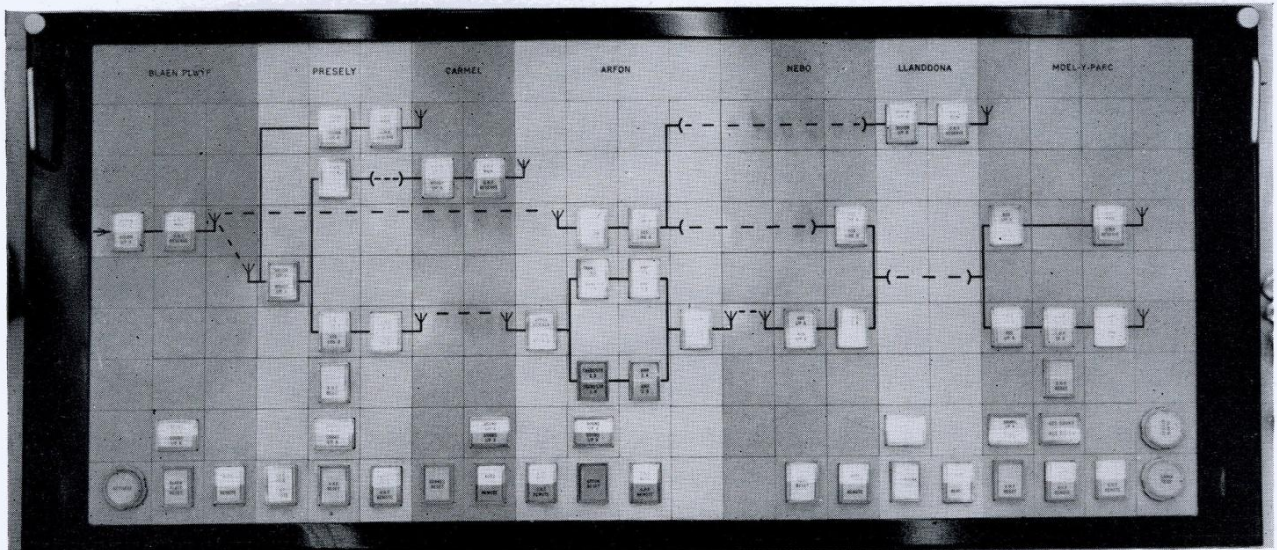


Fig.11. Where the number of key and lamp panels becomes large as at Moel-y-Parc, the panel is specially designed to provide essential information to the operators in the form of a mimic diagram, showing the relationship of the various UHF and VHF stations and indicating which of the alternative sets of equipment are in use.

Moel-y-Parc Control Room

The network in West and North Wales is different from previous radial networks in that the programme is distributed by a chain of transmitters in 'series' rather than by one crucial station feeding several satellites in 'parallel'. A monitoring control room has been set up at one end with one Teledac* master controlling all the stations in the chain. To handle the relatively large volume of information at a reasonable rate, the signalling speed is raised to 600 bits/sec. over a rented PO circuit.

The number of key and lamp panels becomes large due to the variety of station types, so, to improve the interface to the operator, an active mimic diagram was designed to convey the essential information derived

from the Teledac* (see Fig.11). This shows the relationship of the VHF and UHF main stations to one another and which of the duplicated equipment is in use. A fault shows red in the appropriate area of the mimic; first line remedial controls such as selections and resets can be actuated from the desk when necessary. In a difficult case, or before the MMT is dispatched, it is still necessary to make use of the key and lamp panels of the Teledac* to obtain the full details. Fig.12 shows the Teledac* master on the left hand wall and the mimic diagram set in the desk at the Moel-y-Parc control room.

Until recently, most effort has been directed at the 'data acquisition' side of control systems at unattended stations. However, as the volume of



Fig.12. The mimic control panel as installed at Moel-y-Parc, North Wales in the colour control centre. This area includes a chain rather than a radial group of transmitters and the control room is at one end of the chain and has a single Teledac master control for all stations. The data rate is 600 bits/second over a rented PO circuit.

information steadily increases with the growing network, more attention has to be paid to the ergonomics of the interface to the operator. There is scope for completely automating the data acquisition and for presenting the information at various levels of detail to the operator, to enable him to assess the priority to new events as they are telemetered. Mimic diagrams are usually popular but can be expensive and space consuming. The Moel-y-Parc diagram represents one of the first steps in the improvements which are becoming necessary.

Acknowledgement

* The names "Teledac", "Telecode" and "Teleconnect" are trade names of GEC-Elliott Process Automation Ltd.

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Aerials and Channel-combining Equipment for UHF Transmitting Stations

Synopsis

The UHF network is based on co-sited transmitting stations at which both IBA and BBC transmissions are radiated from a single mast using four-channel or occasionally two two-channel aerials with the programme feeds usually received 'off-air'. Such a system requires careful design of

transmitting and receiving aerials as well as channel combining units. This section describes the types of aerials used together with details of the specifications they meet both for the high power main stations and for the lower power relays.

An integral part of the planning of the UHF station network is that the aerial systems should be capable of multichannel operation; while in some cases two 2-channel transmitting aerials have been used the great majority are 4-channel. Suitable channel combining equipment has been developed to permit both the IBA and BBC transmissions to be radiated from one mast; the IBA is responsible for providing this common equipment at those sites for which it is 'landlord'. Most of the equipment is provided by UK aerial contractors; the relay transmitting aerials and the standard receiving aerials are based on BBC designs.

Main Station Transmitting Aerials

The required maximum effective radiated power (ERP) of main stations ranges from 1 MW down to 20 kW but the majority of stations have an ERP of 100 kW and an omnidirectional horizontal radiation pattern (HRP). In some cases the higher ERPs are achieved with aerial apertures of up to 32 wavelengths, but the optimum solution for the 100 kW requirement is a 16-wavelength omnidirectional radiator mounted as a cantilever on the support structure (often a 500 ft. mast).

SUMMARY OF 100 kW AERIAL SPECIFICATION

HRP: Omnidirectional ± 2.5 dB

VRP: Beam tilt angle—defined angle between 1° and 2° below horizontal.

Vertical Aperture: 16 wavelengths

Variation of Radiation with Frequency: Ratio of

Max/Min ERP in any direction for angles below the horizontal between 0° and 4° —not to exceed: within channel 2 dB; between channels 4 dB

Polarisation: Horizontal

Nominal System Impedance: 50 ohms

System Gain: Sufficient to achieve 100 kW ERP with available transmitter power of 8 kW peak sync. vision at input to main feeders.

Two major UK aerial contractors have developed successful designs, one based on the use of dipole radiator panels mounted on a lattice spine and the other making use of slot radiator panels supported within a 3 ft diameter structural glass reinforced plastic (GRP) cylinder.

The former has 4 panels per tier, arranged as shown in Fig.1. Each panel consists of 4 dipoles, spaced $\lambda/2$, resulting in an aerial of 8 tiers. The feeder to each panel is gas-sealed at the input point but the distribution within the panel is by means of strip line and the panel itself is unpressurised. To achieve the required vertical radiation pattern, variable amplitude and phase control of the radiating currents is employed. The close placing (in plan) of the panels on the small square section results in a good omni-directional horizontal-radiation-pattern which is usually well within the ± 2.5 dB limits specified.

Access for inspection and maintenance is provided by a ladder mounted diagonally between a spine corner and the GRP cylinder which provides weather protection—individual GRP covers are installed in the panels for mechanical protection.



Fig.1. Dipole radiators mounted on a lattice spine – one of the two main types of aerial structures used on the high-power UHF transmitting stations. There are four panels per tier with each panel comprising four dipoles, spaced a half-wavelength apart, resulting in an 8-tier aerial. The omni-directional radiation patterns of these aerials are usually well within the ± 2.5 dB limits which are normally specified. (Courtesy Marconi Communication Systems Ltd.)

With the aerial design based on a 3 ft. diameter structural GRP cylinder, access is provided by means of a ladder mounted in the centre. The aluminium slot radiator panels are disposed symmetrically in the form of a triangle against the inside walls of the cylinder giving three panels per tier with four 4λ tiers. Each panel has an internal strip line distribution feeder but a gas sealed connector is used at the input.

Phase perturbation of the radiating currents is used to obtain the specified beam tilt and null fill. Probes are installed at the panel inputs to measure the currents and the necessary adjustments to meet the specified

vertical radiation pattern (VRP) are carried out during the works testing of the assembled array. At site the aerials are lifted and installed in one piece and no measurements other than an impedance check with the main feeders connected are usually necessary. The required impedance performance is sufficiently stringent as to ensure that all reradiated signals are at least 38 dB below the primary image.

Photographs of the aerials and typical radiation patterns are shown in Figs.2,3,4 and 5.

Both aerial system designs are based on the use of a split feed arrangement with two main feeders applying equal amplitude currents to each part.

The main feeders are usually $3\frac{1}{8}$ -in. size semi-flexible type which have proved reliable in operation and convenient to install.

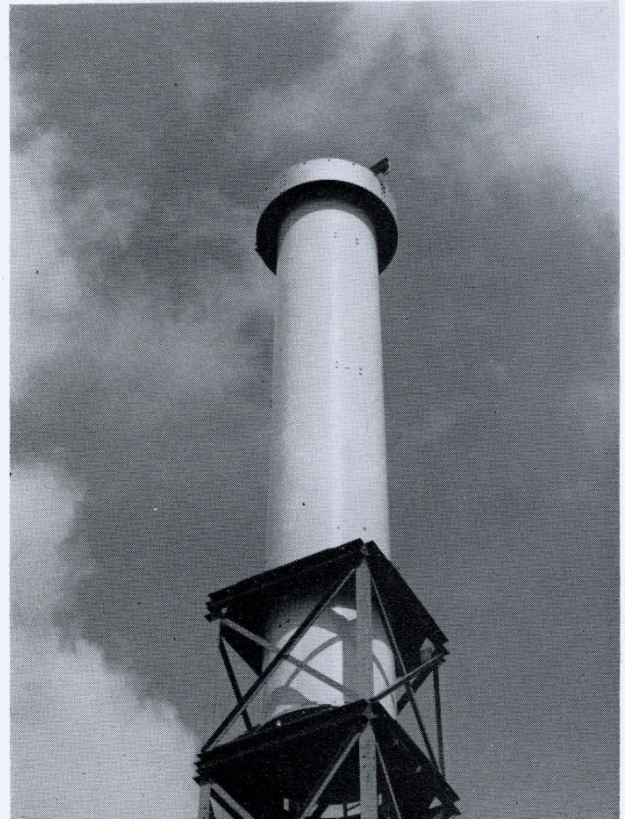


Fig.2. Typical form of a high-power UHF aerial mounted within a 3 ft. diameter cylinder of glass-reinforced plastics which provides good protection against the effects of the weather. Access to the aerial panels for inspection or maintenance is provided by means of the ladder mounted in the centre with the panels in the form of a triangle. (Courtesy EMI Sound & Vision Equipment Ltd.)

Relay Station Transmitting Aerials

During the early stages of the network development most relay station aerials were 16- or 8-wavelength cantilevers mounted on 150 ft. towers. The vertically polarised dipole radiating elements are fixed to an aluminium channel section containing the distribution

feeder system and arranged to give a cardioid horizontal radiation pattern. The aerial is supported inside a structural glass-reinforced plastics cylinder of either 3 ft. or 16-in. diameter presenting a clean uncluttered silhouette which is generally acceptable to planning authorities.

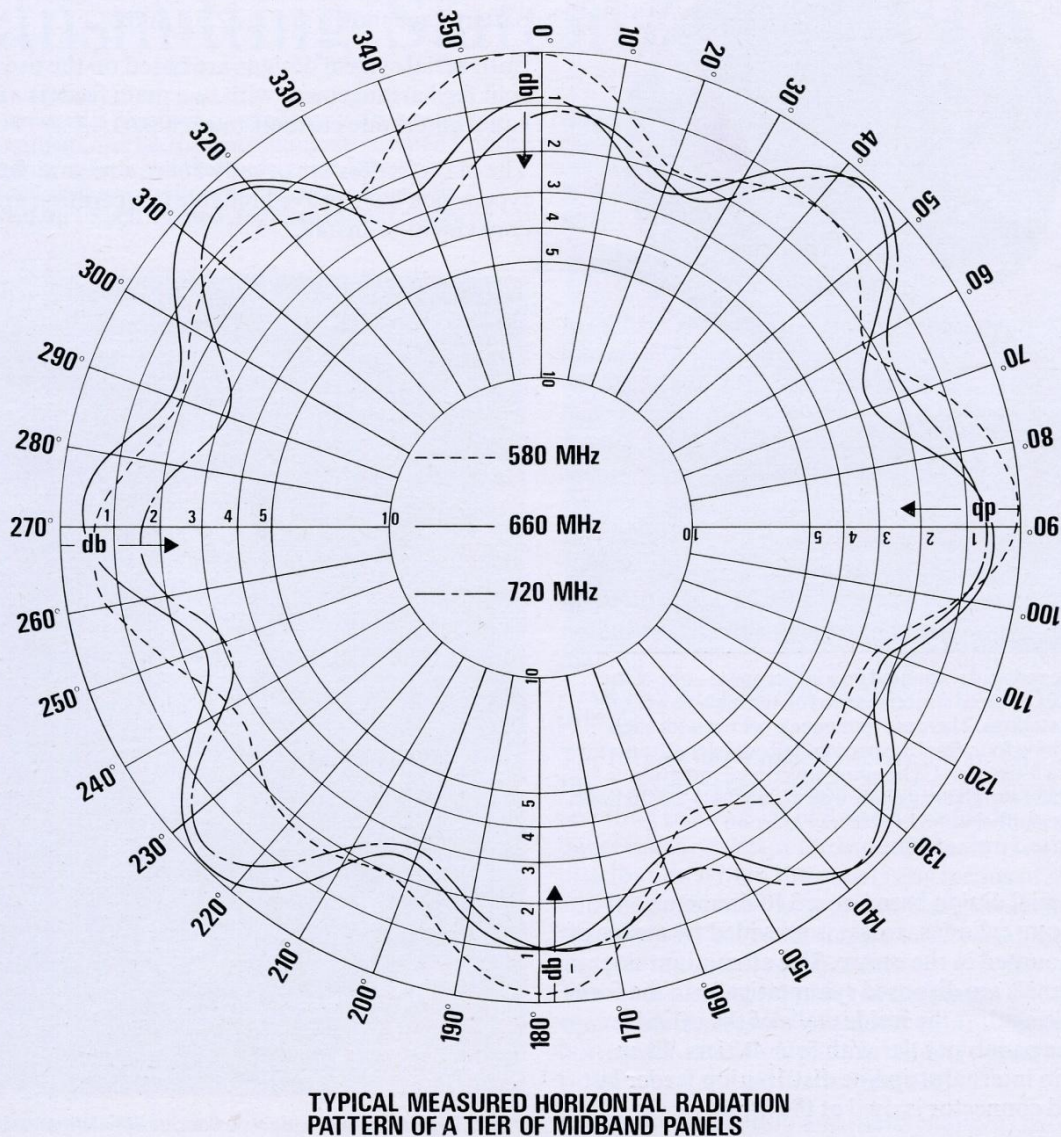


Fig.3. The measured horizontal radiation pattern of a tier of midband panels as used to form a typical 100 kW ERP UHF aerial, maximum variation at 660 MHz is less than ± 2.5 dB.

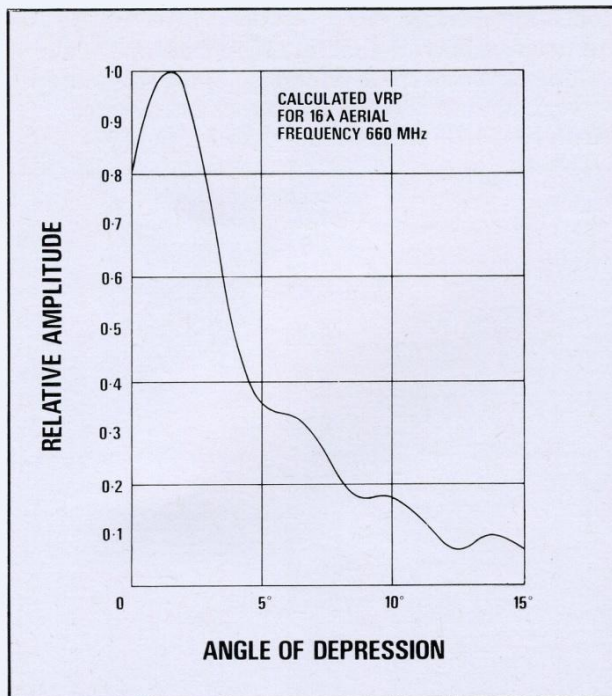


Fig.4. The calculated vertical radiation pattern of a 16-wavelength aerial at 660 MHz showing the main lobe tilted slightly downwards.

While the cardioid pattern aerial is still being provided at many sites the majority of stations to be built in future will require directional patterns since as the network expands more attention must be given to reducing co-channel interference. A vertically-polarised printed-circuit panel aerial has been developed with the required directional characteristics. The panel is a convenient unit which can be used as a 'building brick' in producing various directional patterns as shown in Fig.7.

Two bat-wing radiating elements are printed on glass-fibre laminate spaced $\lambda/4$ from an aluminium reflector and are fixed one wavelength apart to give a 2λ panel as illustrated in Fig.6. The arrangement is fed by a Pawsey stub balun and two types of panel are available – one covering Band IV (470 MHz – 582 MHz) and the other Band V (614 MHz – 855 MHz). The impedance characteristic gives a maximum reflection coefficient of about 6% across the band. A shaped GRP cover is fixed to the front of the panel to give full weather and mechanical protection.

This type of aerial usually consists of two tiers of panels enabling each half to be fed by separate main feeders but at the lowest power stations where only a

single set of transmitting equipment is normally installed it is common practice to use a single feeder for reasons of economy. Typical mid-band intrinsic aerial gains with respect to a $\lambda/2$ dipole of two-tier arrays are as follows:

	BAND IV	BAND V
1 panel per tier	13.0 dB	13.7 dB
2 panels set at 90°	10.7 dB	11.3 dB
2 panels set at 120°	10.3 dB	10.9 dB

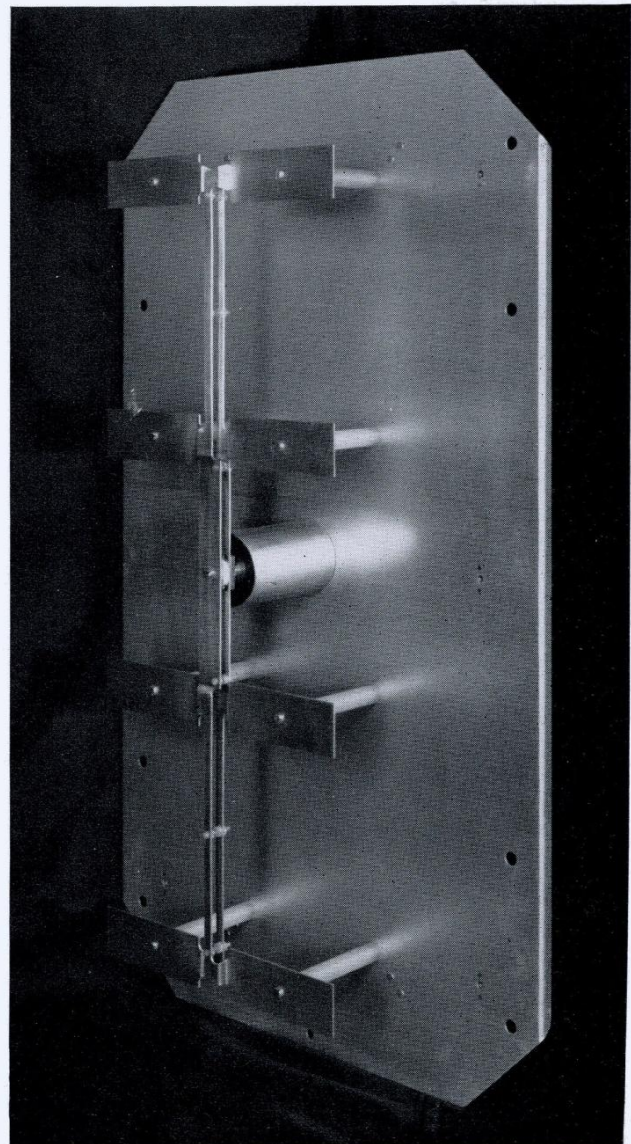


Fig.5. A dipole panel as used at a 100 kW ERP transmitting station. (Courtesy Marconi Communication Systems Ltd.)

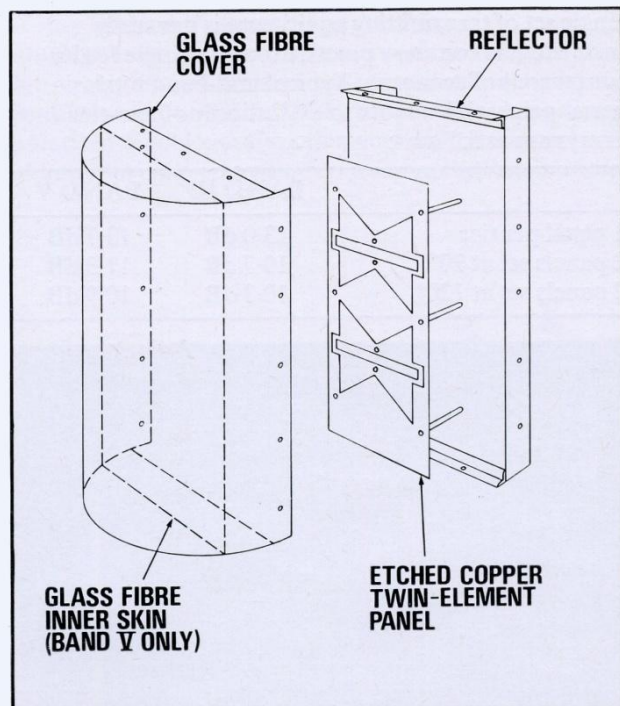


Fig. 6. A twin-element vertically-polarized 'batwing' printed-circuit aerial panel mounted within its glass reinforced plastic cover of either 3 ft. or 16-in. diameter and providing a clean, uncluttered silhouette.

Power rating of the panels arranged in 2 tiers is such that they can be used for transposer powers of up to 200 W per channel.

With the first null in the VRP occurring at about 15° below the horizontal for the two-tier arrangement, null filling is usually unnecessary but if it is required this can be easily achieved by unequal power division between the tiers.

While the normal arrangement is two tiers some multi-tiered arrangements have been built, as illustrated in Fig. 8.

All the distribution feeder system components for the panel arrays are designed to be operated unpressurised and while the main feeders are semi-air spaced, the feeders are terminated in special sealed connectors which obviate the requirement for a dehydrator. A silica gel breather unit open to the atmosphere is fitted to the lower end connector to ensure that dry air is admitted to equalise any pressure changes. The elimination of a dehydrator with its moving parts is a very important advantage for the low power relays where maintenance visits are likely only once or twice a year.

Receiving Aerials

The problem of co-channel interference is one of the limiting factors in the development of the UHF station network and the implications of such interference were taken fully into account in the design of the

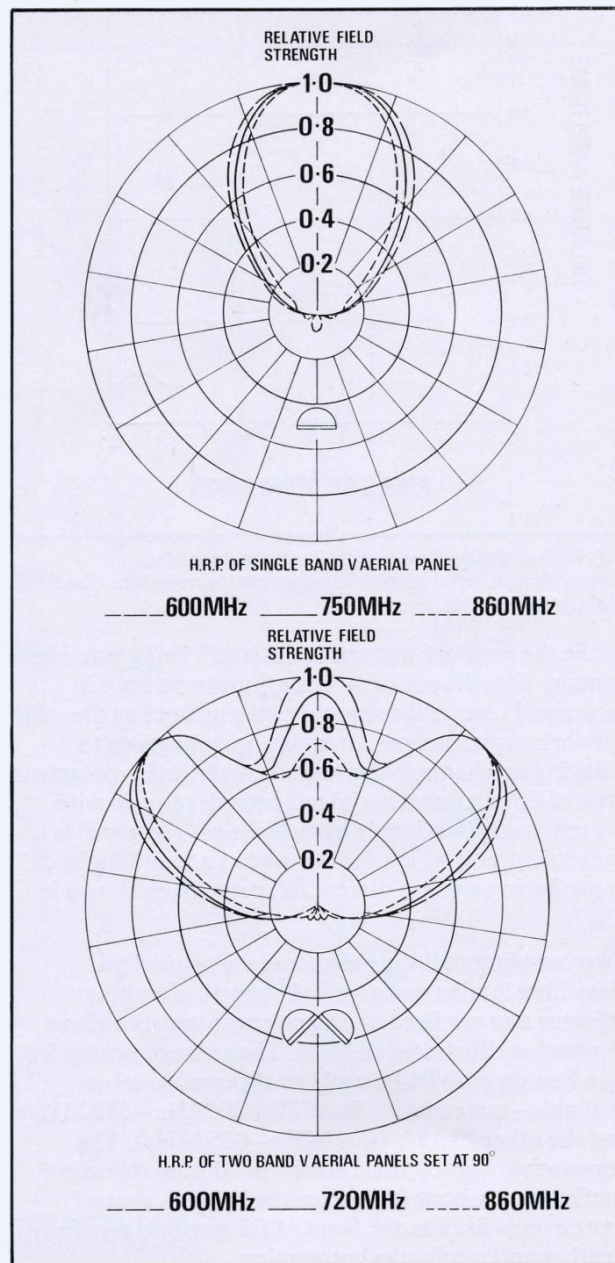


Fig. 7. Typical horizontal radiation patterns of Band V batwing vertically polarised aerials of the type shown in Fig. 6. The upper diagram shows the pattern of a single panel, the lower diagram that of two panels set at 90° to each other.

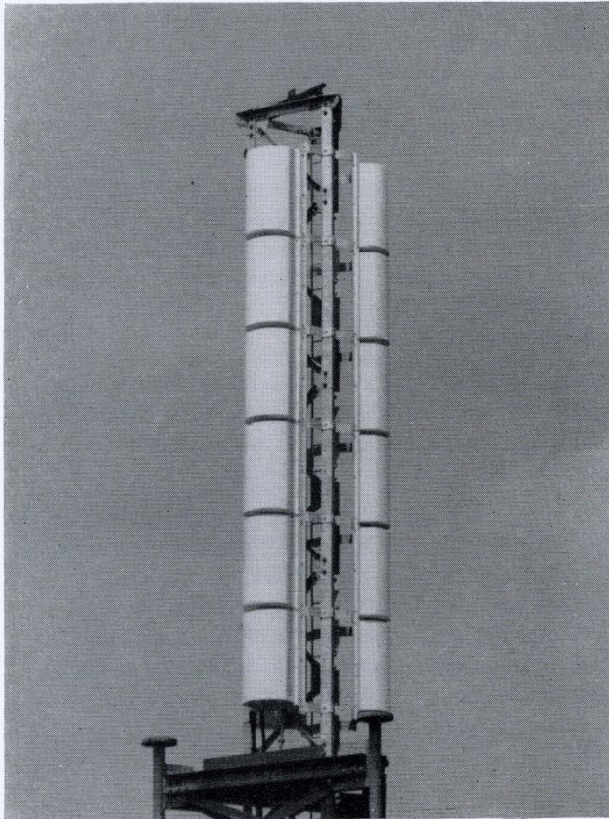


Fig.8. A multi-tiered panel aerial which in this case consists of six tiers. (Courtesy EMI Sound & Vision Equipment Ltd.)

four-channel receiving aerial used at both main and relay stations. A trough reflector containing four $\lambda/2$ dipoles mounted on Pawsey stubs is arranged to give minimum side lobes and backward radiation, at least 22 dB down on the main lobe which has a beamwidth of about 17° . To achieve the required pattern it is necessary to feed the dipoles across the array with co-phased currents with a current amplitude ratio of 1:2:2:1. Three models are required to cover the UHF band with intrinsic gains varying from 14 dB for the Band IV unit to 15.5 dB for the upper Band V version. Dimensions of the largest (Band IV) is 2.10m \times 0.79m \times 0.33m which represents a significant wind-loaded area to be taken into account in the design of the support structure. The reflector and dipoles are fabricated from aluminium and weather protection is afforded by a GRP cover across the front. This type of aerial has proved to be extremely reliable in service and is likely to be used for some years to come.

However, at the lowest power relay stations serving

very small populations the cost of the support structure and aerial systems represents a substantial proportion of the total station cost and it would be an advantage if the wind-loaded area of the receiving aerial could be reduced. Consideration is therefore being given to alternatives such as the log-periodic and yagi. Unfortunately this would result in some sacrifice in performance and this has limited progress.

The trough reflector is used for the reception of horizontally polarised signals from main stations but in some cases (e.g. when relay stations are operated in tandem) it is necessary to receive a vertically polarised transmission. Some work has been done on vertically polarised log periodics and it seems likely that arrays of such elements can have a performance approaching that of trough aerials for horizontally polarised transmissions.

Channel Combining Equipment

When considering television transmissions in the UHF Band it is a relatively simple exercise to show that in order to produce the large ERP required (in some cases as high as 1 MW) the least expensive solution is to provide aerials of very high gain. Fortunately, since the wavelength in Bands IV/V is relatively short, a high gain array can be produced occupying a vertical radiating aperture of no more than 10 metres or so. Nevertheless, it is usually technically undesirable (and often impossible) to employ separate transmitting aerials for each channel due to the radiating height gain variations, loading restrictions on the support structure, etc. In the UK frequency planning for the UHF Bands, the group of 4 channels allocated to any one station normally occupies a frequency spectrum of only 88 MHz making the production of an aerial suitable for use on all channels simultaneously feasible. This, however, creates a fresh problem: the need to provide a combining unit to combine two or more wide-band channels, spaced usually some two or three or more channel-widths apart, into a common transmission line and transmitting aerial system.

Of the different configurations of equipments that could be used to achieve this combining function, two basic forms are employed, one type exclusively for the high power UHF main stations and the other primarily for the low power UHF relay stations.

High Power Combining Equipments

A schematic diagram of the major part of a high power combining equipment is shown in Fig.9. This design

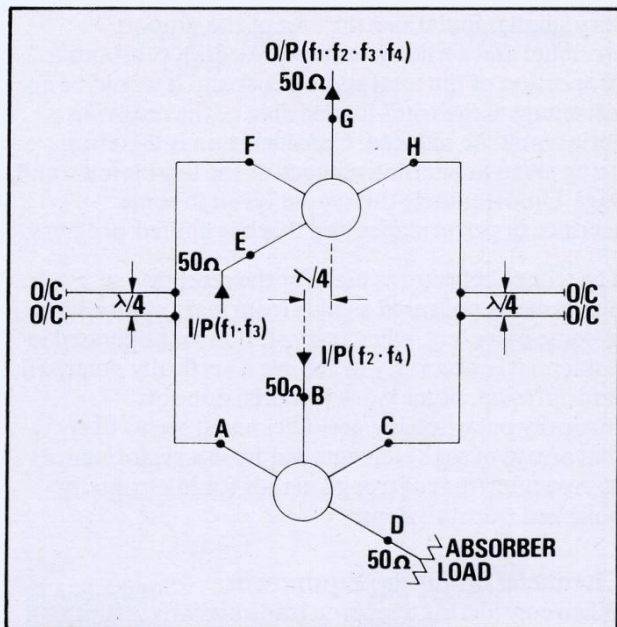


Fig.9. A schematic diagram of a high power UHF combining unit using a pair of 90° hybrid rings linked in the Lorentz configuration and using long-line co-axial resonators to provide the required frequency-selective characteristics. The operation of this type of combining unit is described in the text.

employs a pair of 90° hybrid rings linked together in the Lorentz configuration using long-line co-axial resonators to give the required frequency selective characteristics.

The operation of the equipment is quite straightforward. Power at frequencies f_2 and f_4 enters the lower hybrid at port B and is split to emerge at ports A and C in a co-phase condition. The power then flows along lines AF and CH encountering on the way the two filter assemblies. These long line resonators are of such a length that at frequencies f_2 and f_4 , they present a nominal open circuit across the line. As there are two stubs in each filter assembly, spaced a quarter of a wavelength apart, any slight discrepancy in the desired high impedance condition, which would otherwise cause a mis-match, is approximately cancelled out. If, however, any reflection does occur at these filters, due to the quarter-wave staggering of the two assemblies with respect to the hybrid, the reflected waves arrive back at the hybrid ports A and C in an antiphase condition and are thus diverted to the absorber load. When the power arrives at ports F and H of the upper hybrid due to the equal length of line AF and CH, it arrives co-phased and thus is directed to port G and hence to the aerial.

The input port for power frequencies f_1 and f_3 is port E on the upper hybrid. Power entering this port is split equally between ports F and H emerging in an anti-phase condition. The power then flows away from F and H in the directions of A and C respectively. The filter assemblies at these frequencies are now arranged to appear as short-circuit across FA and HC and virtually total reflection occurs. Due to the quarter-wave staggering of the filter assemblies with respect to the hybrid, the reflected waves arriving back at ports F and H will now be in-phase and the power therefore directed to port G and to the aerial.

Any components of forward waves transmitted along FA and HC which do pass the filters will arrive at A and C still in antiphase and thus will be directed to the absorber load.

Whilst the diagram and description pertain specifically to the combination of interleaved pairs of channels (i.e. f_1 and f_3 together with f_2 and f_4) an identical arrangement can be and is used to combine the constituent channels together into the pairs of channel groups which will be further combined in equipment as described above.

The advantage of this type of equipment over the low power combining equipments described below, is that it possesses a very flat frequency response across of each of its pass bands and because of the resonators exhibits a good isolation characteristic between each of its input ports.

Low Power Combining Equipments

A schematic diagram of this type of equipment is shown in Fig.10. It will be seen that the equipment comprises a pair of 3 dB couplers inter-connected by unequal length lines.

The two directional couplers (I and II) are identical single-quarterwave 3 dB couplers. Power at frequencies f_1 and f_3 when connected to port E will be split so that half the power appears at port F and the remaining half at port G. By virtue of the balance of the coupler, port H is completely de-coupled. The phase of the voltages appearing at port G will lag those at port F by 90° . In an equivalent manner, power at frequencies f_2 and f_4 when applied at port H will be similarly divided and port E decoupled. In this case the phase of the voltages at port F will lag those at port G by 90° .

The commuting line is made considerably longer than the link line and is approximately one-half wavelength longer at the difference frequency between adjacent

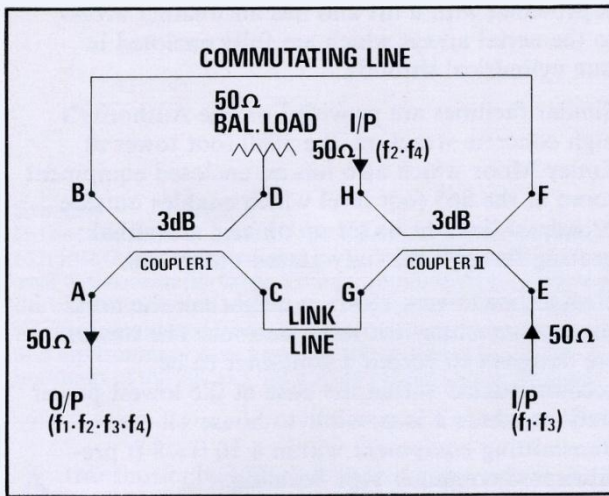


Fig. 10. A low power UHF combining unit which consists basically of a pair of 3 dB couplers inter-connected by unequal length lines.

channels (i.e. $\lambda/2$ at frequency $f_2 - f_1$). Now, consider the condition when this difference in length between cables is an odd number of half-wavelengths at frequencies f_1 and f_2 . The voltages at these frequencies arriving at port D of coupler I via ports B and C will be equal in magnitude but in antiphase and so no power will be dissipated in the balancing load. On the other hand, the voltages arriving at port A will be in phase and so all the power entering at port E will emerge at port A.

Consider now the power entering at port H at frequencies f_2 and f_4 which are such that the difference in length between the link and commuting lines is an even number of half-wavelengths. In a similar fashion to the power entering at port E, that entering at port H will also emerge at port A with no power dissipated in the balancing load at port D.

Since with any normal group of frequency allocations for a station, the spacing between adjacent channels in the group is not precisely equal, commutation cannot be exact over complete channels and a small amount of power will be dissipated in the balancing load.

As in the case of high power combining units, the individual channels are combined into the channel groups using almost identical equipment to that used for the final combination.

Whilst this relatively simple equipment is virtually maintenance free, it does have the disadvantage of the progressive change in phase lengths of the long coaxial line with frequency for its frequency selective properties. This results in an insertion loss which varies both within

and between each of its pass bands. Whilst such variations may be acceptable when a signal is passed along a chain of one or two stations containing this type of equipment, for long chains of relay stations such variations can cause distortion of the signal characteristics to such an extent that correction must be applied at some point in the chain.

Channel Separating Equipment

The standard receiving aerial is a multichannel device and it is necessary to separate the combined signal into its component channels. This is done by means of a filter which provides individual feeds for each channel of the receiving/transposing equipment.

Equipment performing this function could be designed by applying inversely either of the principles previously described for channel combining equipment. In practice, the principle of the low power combining unit is used for the splitting function because of its simplicity, ease of maintenance, and low cost. From Fig. 10 it can be seen that if the signal from the receiving aerial is fed in at the normal output port, the

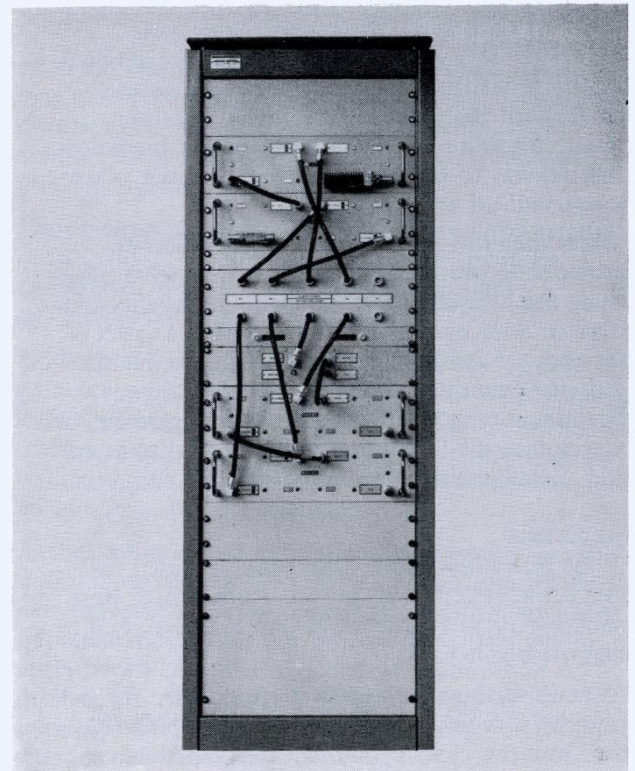


Fig. 11. The channel splitting and channel combining units as assembled into a single cabinet for the lower power relay stations.

constituent channel components will appear at the points labelled as input ports. A single unit of this type, when fed with a four channel input, splits down to a pair of interleaved channels at each output. To split down to single channels thus requires the provision of further units added in cascade with the main splitter.

Fig.11 shows a channel splitting and channel combining complex assembled into one cabinet as used at the lower power relay stations.

Aerial Monitoring and Protection Equipment

At the majority of UHF main stations, in spite of the fact that high gain transmitting aerials are employed, the transmitter powers necessary to achieve the very large ERPs required are still very large. Now, every transmitting aerial and feeder system is designed with some factor of safety on its normal power and voltage handling requirements, however, it is often uneconomic and sometimes even impossible to design a feeder system which is able to accept the additional power delivered to it by say a transmitter with a modulator fault. In addition, if some minor fault in part of the aerial system occurs resulting in a large voltage standing wave ratio, there is a considerable possibility of a voltage breakdown being initiated. Such a breakdown may release ionised gases throughout the air-spaced distribution feeder system leading subsequently to a major breakdown and damage to the aerial if the transmitter power is not shut-off as soon as possible.

It is therefore essential that equipment be provided to protect the aerial against excess power being fed to it and to monitor any high reflections from it. Such equipments are provided as part of the channel combining complexes and in its most general format it comprises accurately aligned directional couplers and pairs of power meters, one monitoring the forward power being fed to aerial and the other the reflected power from the aerial.

Structures

While many new masts have been provided for UHF aerial systems existing structures which were built for the VHF network have often been used to support UHF aerials.

At main stations the aerials are supported on stayed lattice masts ranging in height up to 1000 feet. In a few cases cylindrical steel masts have been built including the highest mast in the U.K., the 1265 foot Belmont structure. This type of mast

is provided with a lift and has all weather access to the aerial arrays which are fully enclosed in GRP cylindrical shrouds.

Similar facilities are provided on the Authority's high concrete structure, the 1080 foot tower at Emley Moor which also has an enclosed equipment room at the 865 foot level which enables outside broadcast links to be set up on any azimuthal bearing through the fully glazed outer wall.

Steel lattice towers 150 ft in height are the usual support structures for relay stations. The towers are designed to permit a container to be accommodated within the base at the lowest power stations where it is possible to house all the transmitting equipment within a 10 ft x 8 ft pre-fabricated container type building.

A 'slim line' design tower has now been adopted which has a constant tapered 'see through' silhouette which many local planning authorities prefer to the conventional parallel-sided top portion type.

References

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Transmitter Station Buildings

Synopsis

In the early days of Band III television the building needed to house the transmitters and the number of operational staff was necessarily large. Often located on remote hill-tops the transmitters and staff had to be decently housed, but it was also recognised from the outset that questions of amenity and environment were also important, and many of the buildings of the 50s and 60s were not without architectural

merit. With the coming of the new unattended UHF stations it became possible to reduce the technical areas and buildings have become more functional. Nevertheless the same basic approach to good building practice and design has continued, and forms an important part of the work of the Station Design and Construction Department. This section includes an outline of recent developments in buildings for main and relay stations.

A transmitter building is designed as a weatherproof and secure enclosure for the complex technical equipment and to provide reasonable conditions of comfort for staff required to install and commission the equipment and subsequently to maintain the station. Ancillary services such as water supply, roads and drainage form a necessary part of the project.

Although the majority of buildings are needed to sustain the continuing build-up of the UHF television network, some are also required for Independent Local Radio and for external organisations, such as the Post Office and the Home Office, under various mast sharing arrangements. These may or may not be attached to or form an integral part of a transmitter building. Under a joint site-sharing agreement accommodation is also provided for the BBC on IBA-owned sites and vice-versa.

Architects in private practice and other consultants may be appointed to undertake the detailed design and administration of contracts, but most of this work is now carried out by staff architects and engineers of the IBA. The group concerned with buildings aims to be financially self-accounting, taking into account overheads appropriate to a private practice of comparable size.

Building contracts are generally based on the Joint Contracts Tribunal Standard Form of Building Contract and are awarded on the basis of competitive tender. However, in some parts of the country, conditions make it necessary to negotiate a price with a suitable contractor.

Planning and Amenity

The UK is densely populated and there are conflicting demands on the space available for expansion and

recreation. About 12% of the area of England and Wales is now 'built-up' or developed in some way or another; another 40% or so is protected as national parks, areas of outstanding natural beauty, areas of great landscape historic or scenic value, or as national nature reserves. Much of the remainder is good agricultural land.

In comparison with some other industries, the area of land required for a television or radio station is relatively small. Exceptionally, several acres of land may be required for a radio station with a four-mast directional MF aerial array but, more generally, an area of 30m × 20m is all that is required for the low-power UHF relay stations.

The siting requirements for the modern UHF transmitter or MF radio station are exacting and, for any given service area, there are few locations which are technically satisfactory on all counts.

Unlike many other statutory bodies, the IBA does not possess power to acquire sites by compulsory purchase; it is therefore necessary to negotiate terms with the owners and agents concerned, subject to obtaining outline planning and other consents of the various authorities and bodies involved.

At the outline and detailed planning consent stages it is necessary to agree with a local planning authority the external form of the building and the type of material to be used in its construction. In most cases the planning authority will accept a brick or rendered finish to external walls but, in areas of high amenity value, buildings may have to be constructed of natural stone in character with the area.

However, irrespective of any standards that may be required by a planning authority, care is always taken by

the IBA to ensure that the building complex is properly related to its surroundings. Provision is also made for possible future extension both to simplify this and to avoid fragmented development of the site.

In some cases it has been possible to arrange the buildings about a central forecourt (Fig.3). The single forecourt serves both the UHF and VHF stations whilst the enclosure walls afford security and some protection against inclement weather for operational staff visiting the site. Need for maintenance of the external areas is minimal and land beyond the perimeter walls is returned to full agricultural use.

Wind

Even with a relatively low profile structure it is necessary to take account of wind forces considered in relation to exposure, topography, shape and permeability of the building. A combination of negative pressure at roof level and positive pressure within a building can, on a flat roofed building, result in total uplift forces in excess of 290 N/m². This makes it essential to give close attention to design and detailing, particularly the walls and roof.

With traditional forms of construction, the ability of brick walls to withstand lateral loading is very considerably improved by the existence of internal cross walls and a superimposed load; it is mainly for this reason that pre-cast concrete roof units and solid internal walls are preferred to lighter and less expensive forms of construction.

Site Investigation

Where necessary, an investigation is carried out into sub-soil conditions to determine the basic engineering properties of the soil. This work usually involves the excavation of trial pits and, less frequently, soft ground boring using shell and auger, logging ground conditions and obtaining samples of soil and ground water for subsequent analysis in a soils-testing laboratory. An investigation of this type can usually be undertaken at a moderate cost. The advance knowledge of subsoil conditions results in a properly designed foundation and minimises problems during and after construction. At one site, the ground water was found to have a pH value approaching 3.0: so acidic that it was necessary to wrap the concrete foundation in butyl rubber fabric to protect work below ground against chemical attack.

Mining Subsidence

It is becoming increasingly necessary to construct buildings in areas where the ground is subject to

movement due to mineral extraction and subsidence. Most damage to buildings and structures is caused by differential movement of the ground at the surface. When building in a mining area, the fullest possible investigation must be carried out into local geology and the extent of past, present and possible future workings, balancing the cost of investigation and extent of any remedial work required against the nature of the risk involved in the event of structural failure or collapse. The assessment of ground stability problems are essentially empirical in nature; accurate evaluation depends primarily upon the validity of the information available, particularly about past workings.

In designing the relatively small buildings required for transmitting stations, it may be necessary to allow for small differential horizontal strains by taking measures to reduce the effects of friction between the ground and building foundation.

Fire Prevention

With the exception of joinery and certain types of finishes, the majority of transmitter buildings are constructed of non-combustible material. The principal fire prevention need is for equipment that can readily be deployed to deal with any small outbreaks of fire that might occur during installation or when staff are carrying out maintenance work at a station.

With few exceptions, total flooding systems are not used: dependence is placed upon portable wall and trolley mounted vapourising liquid and carbon dioxide extinguishers placed at convenient points about the building. Additionally, asbestos blankets are supplied to stations where domestic cookers and other appliances are installed.

Industrialised Building

All new transmitter buildings contain factory-made material such as blocks and pre-stressed concrete roof units, but the steadily rising cost and the scarcity of labour required to assemble and fix components at frequently remote and inhospitable sites, has highlighted the need for alternative and cheaper forms of construction. This is particularly true for the smaller type of building required to meet the needs of a continually developing UHF network of transmitters.

Considerable time and effort are required to develop designs and to prepare satisfactory standard details for the assembly of components which are commercially available or which can be manufactured at low cost. Repetition and continuity are essential ingredients for the success of any industrialised system

but choice is also conditioned by volume and by the ease and cost of transporting components or the finished product to its final destination.

Development of Low-power Relay Stations

The large number of relatively low power relay stations required to serve the remoter and less populous areas, coupled with the high cost of traditional building, prompted a detailed re-appraisal of methods and techniques for building small stations.

A number of options were examined including the possibility of combining a stayed tubular steel mast with a housing firmly secured to the structure at its base. Though visually attractive, a solution along these lines was considered rather more costly than a solution based on a free standing tower and building, so an evaluation was made of various proprietary industrialised systems including those using pre-cast concrete, steel and reinforced plastic.

The main requirement was for a robust, weather proof, durable and reasonably maintenance free housing for the transposer equipment which, if possible, could be produced under factory conditions and assembled before delivery to site.

The steel container industry is highly industrialised and has accumulated a great deal of expertise in manufacturing all-welded steel containers for sea, road and rail-borne freight to British and international standards.

Following discussion with manufacturers, a contract was placed for a prototype all-welded 16 SWG profiled mild-steel shell, complete with porch recess, electricity meter cubicle, electrical wiring and mechanical ventilation equipment. The nominal overall dimensions were chosen to conform with international standards to give the minimum acceptable size of housing in which the technical equipment for the IBA and BBC services could be contained.

The housing was lined and insulated to give a U value of $0.5W/m^2/^\circ C$ for walls and roof to minimise internal temperature fluctuation by reducing solar gain during summer and heat loss during winter. Most of the heat generated by the equipment is removed by two thermostatically controlled fans capable of operating singly or in combination to give well over 100 air changes per hour if required, to limit the internal temperature rise of the unit to $33^\circ C$.

A purpose-built vehicle enables the complete unit to be transported to site and positioned within the base of a



Fig.1. A transportable pre-fabricated steel-framed 'container' building for a low-power all-solid-state local relay station arrives on site on a purpose-built vehicle and can then be unloaded without the use of a crane or other special local equipment. The container is pre-wired and later it is expected that much of the equipment will be fitted before it is taken to the site of the station.

standard steel tower. This type of unit is shown on its special vehicle in Fig.1 and as finally installed in Fig.2.

The concept has been further extended and developed and transportable steel framed housings are now equipped and fully operational at a number of sites throughout the country with substantial savings in capital, management and staff costs. No attempt has yet been made to transport the cabin unit with the technical equipment in position, but further financial

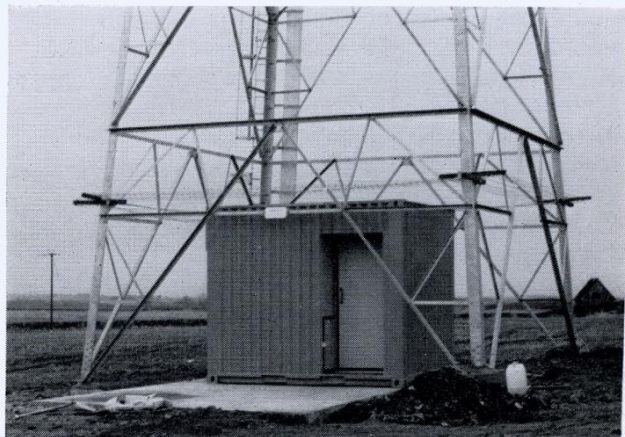


Fig.2. The IBA steel 'container' building in position within the base of the aerial tower. Four 10-watt all-solid-state transposer-transmitters and all ancillary equipment can be housed within the building.

savings seem likely when equipment, possibly on resilient mountings, can be installed in the unit and tested before consignment to site.

Prefabricated units can be designed and manufactured to whatever standards are required and to suit whatever means of transport are available. Units can be made sufficiently light to bring pay loads within the economic lifting capacity of the commercial helicopter or sufficiently robust to enable them to be dragged or skidded over rough terrain where roads may be difficult or very costly to provide.

Evolution of Main Station Building Design

Most of the early high-power main unattended Phase 1 UHF station buildings were built to a high specification, particularly in regard to space and standard of internal finishes. For example, in the main entrance, transmitter and stores areas, electric conduit was concealed beneath a plaster finish and, in the transmitter area, interconnecting services such as power cables, feeders, technical wiring and equipment ducting and pipework were either run above a suspended ceiling or through a network of ducts formed in the floor.

With the increasing total of all types of transmitting stations being built it was decided that, for the Phase 2 main stations, the buildings should be wholly functional in design and appearance and built to a budget reflecting, so far as possible, the purpose for which they were intended.

In tendering for the transmitter and ancillary technical equipment, manufacturers were invited to consider the overall arrangement of the equipment within the station and it was clearly stated that preference would be given to manufacturers who were prepared to design equipment which did not require special features incorporated in the building such as under-floor ducts. It was also decided that the transmitter cooling arrangement should incorporate provision for maintaining the building at stable conditions of temperature and, indirectly, humidity and cleanliness.

Although preliminary details obtained from manufacturers fell short of what was required, their specifications and information provided formed the basis for further dialogue with the successful contractor.

Detailed discussions resulted in a very compact arrangement of the transmitter coolers and associated

electrical equipment. As a measure of what was achieved the ratio of building space to equipment volume was effectively reduced from about 14 on the Phase 1 UHF main stations to four on the Phase 2 main stations.

The principal items of equipment were arranged in three parallel rows so that interconnecting pipe work, feeders and power services could be run on the internal faces of walls and ceilings with a minimum of cross over. Rear access was provided to the transmitters which were conveniently arranged to partition the transmitter and heat exchanger areas.

Most of the Phase 2 buildings are of single-storey cavity wall construction with an inner skin of load-bearing brick or blockwork fairfaced and painted. Roofs are generally constructed of precast or prestressed concrete roof units and finished with screed, insulation, asphalt and asbestos tiles to afford protection against the effects of ice falling from the mast and stay wires and from solar radiation. A representative design is shown in Fig.4.

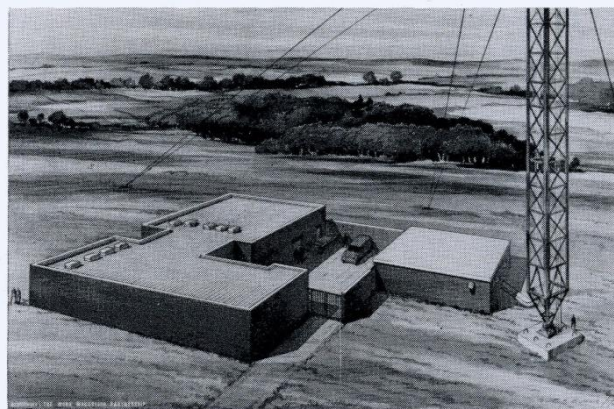


Fig.3. Artist's impression of a representative building design for one of the Phase 1 unattended and co-sited UHF and VHF transmitting stations.

The buildings for the Phase 2 main stations are of such a size and so intensively equipped that it was considered unnecessary to install separate systems for cooling the building and the transmitter equipment. An integral system of cooling was designed to utilise waste heat generated by the vision and sound klystrons and to maintain acceptable temperature conditions throughout the building. In essence, room temperature control is effected by thermostats coupled to motorised dampers that permit fresh, or re-circulated, air to be blown through the transmitters and passed

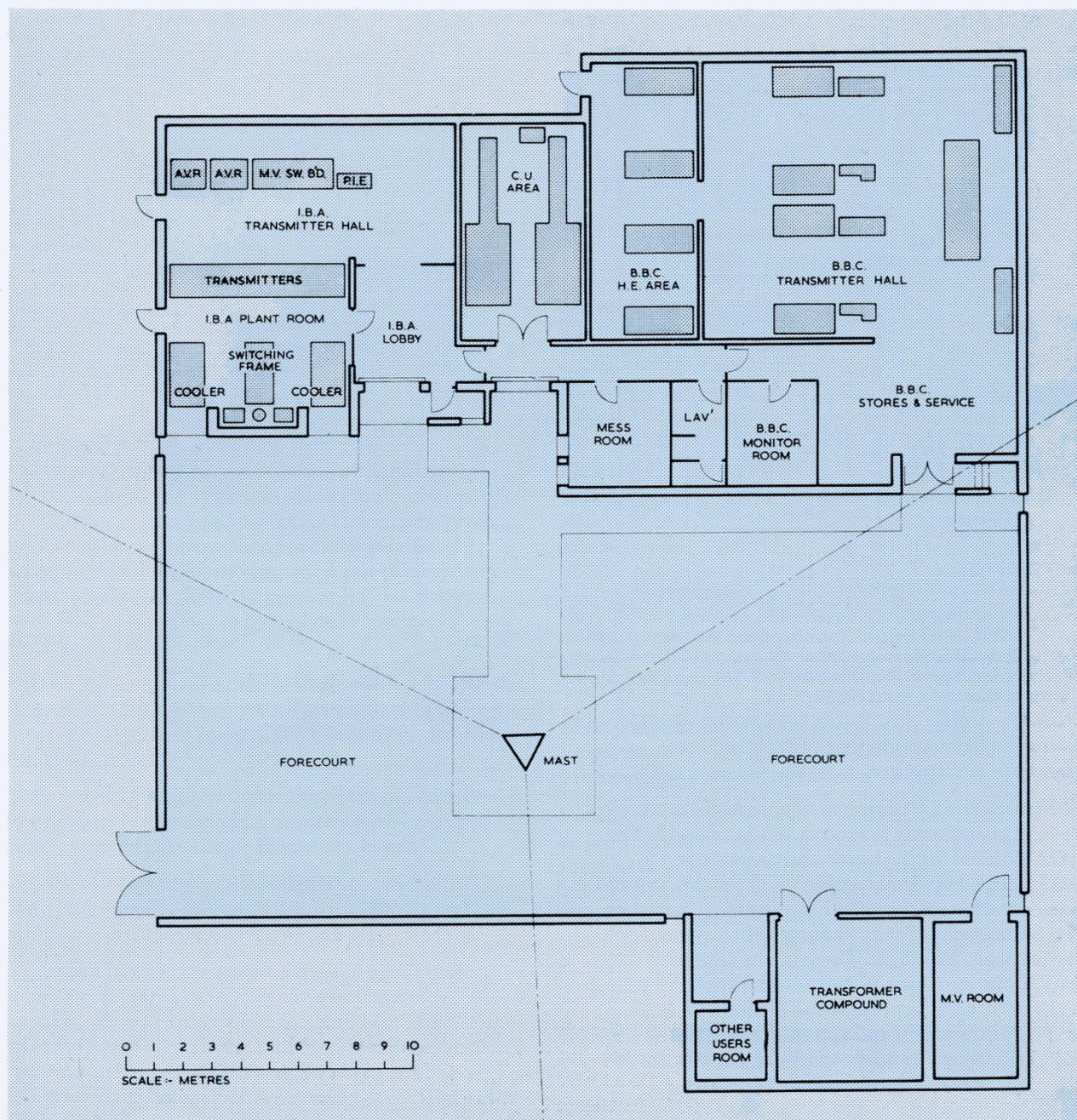


Fig.4. Plan of a UHF main station building complex.

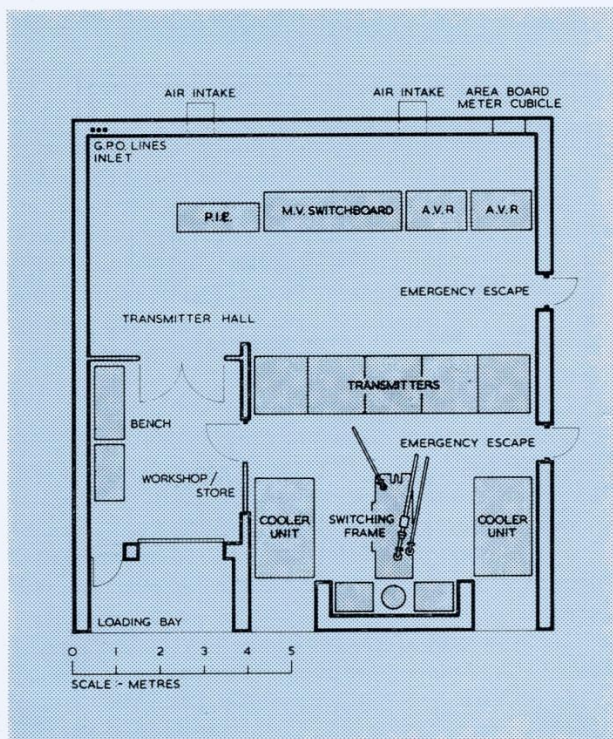


Fig.5. Layout of an IBA Phase 2 main station transmitter building, showing in more detail the arrangement of the transmitters, store and the workshop for maintenance work.

across the steam condensers or exhausted to atmosphere as required.

The layout and arrangement of equipment in a typical Phase 2 main station are shown in Figs.4 and 5. The areas required for the sound and vision channel combining equipment together with the messing and toilet accommodation are shared by the two parties. Provision is made for extending the buildings, if required, at a later date. The small buildings on the lower right-hand side of the central forecourt house, separately, the transformer and medium voltage electrical equipment and apparatus installed by independent users under a mast-sharing agreement.

Power Supplies for Transmitting Stations

Synopsis

All of the IBA transmitting stations depend for their primary source of power on electricity supplies, drawing a total of some 10 megawatts. For main stations it is the usual practice to have duplicate supplies from independent 33/11 kV substations of the Electricity Board's network, with automatic changeover. Because the stations are

unattended effective and rapid isolation of any defective circuits are of special importance. Transmitters also demand power supplies with smaller voltage variations than can be expected from the incoming mains supplies, involving the use of automatic voltage regulation. These and other aspects of power supply practice are described.

The generation and transmission of electricity in England and Wales comes under the control of the Central Electricity Generating Board, who provide bulk supplies to the twelve Area Electricity Boards, responsible for the distribution and sale of electricity to consumers. In Scotland the generation and distribution of electricity is dealt with by two Area Electricity Boards.

Other autonomous Electricity Undertakings within the British Isles from whom the IBA purchase supplies are located in Northern Ireland, the Isle of Man, and the Channel Isles.

The electricity supply to most sites is shared with the BBC and the detailed engineering arrangements are jointly negotiated with the Electricity Boards.

For the stations commissioned up to the end of 1973, the total demand of the IBA loads for both VHF and UHF stations is in the region of ten megawatts (10 MW).

The cost of electricity consumed is a major revenue item. The majority of the supplies are charged in accordance with a maximum demand tariff, which is advantageous because the load factor (utilisation of maximum demand which is registered over a half hourly period) is high, being in the region of 60% at the Phase I Main UHF stations.

An inquiry to an Electricity Board is issued as soon as the exact location of the site and the transmitter load details are known.

The normal experience is that a period of at least twelve months is involved between the initial inquiry to the Electricity Board and the eventual connection of

the supply. During this time the Electricity Board have to negotiate the wayleaves for the agreed scheme and also obtain statutory consents for the erection of any overhead lines involved.

The declared rating of each supply for the combined use of the IBA and the BBC (including provision for a future fourth UHF programme), ranges from 500 kVA to 1000 kVA at main stations, and 15 kVA to 100 kVA for relay stations.

Most transmitting sites are in remote locations and the supply involves an extension of the Electricity Board's overhead line network operated at 11,000 volts.

For the majority of the UHF main stations it has been an economical proposition to arrange for duplicate supplies to be made available from largely independent 33/11 kV substations of the Electricity Board's network. A few stations have IBA diesel generating plant available with automatic start facilities which can restore the supply within about thirty seconds.

Relay stations often rely on a single electricity supply, because it is likely that if this fails the fault would also affect the majority of the receivers in the fairly restricted service area.

The security of the supply is obviously vital to the performance of each station. The 275/132/33 kV national transmission system from the power stations to the 33/11 kV transformer substations is, by the system design, extremely reliable. It is in the 11,000-volt overhead line networks that the majority of the faults occur which interrupt broadcast services.

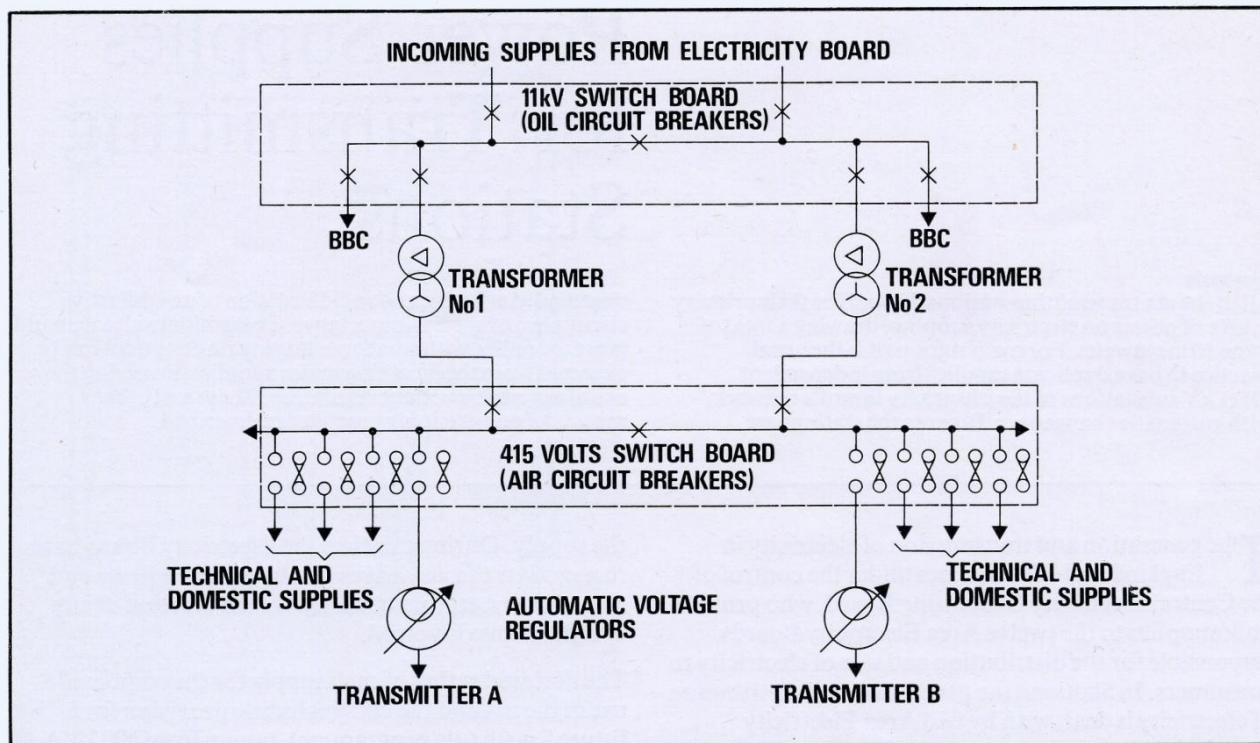


Fig.1. Simplified schematic diagram of power distribution at a representative UHF main station.

In assessing the prospect of reliability of any supply it is in a study of the 11 kV networks that the main differences occur. Such matters as the length of the overhead line involved (usually many miles), the amount and type of automatic reclosing protection employed, and the number of connections to other consumers, are some of the factors which have to be taken into account in considering a particular supply scheme.

The average station in a remote area seems to experience (over a period of several years) an average supply interruption of about two hours per year.

Duplicate supplies which are reasonably independent in their source and routing can reduce the average overall 'outage' time to a few minutes per year.

The IBA and BBC have endeavoured to achieve standardisation of the supply site engineering arrangements for similar load requirements, but (particularly in the case of main stations) differences in the requirements of the various Electricity Boards have affected the design in some cases.

The differences include such matters as the declared

rating at which the supply is delivered and metered at high voltage (11,000 volts) as distinct from medium voltage (415 volts). Also the declared point of supply has affected the metering arrangements and the division of ownership of the high voltage equipment.

Usually the IBA and the BBC are separately metered consumers of the Electricity Board, but at some sites the principle of submetering has been readily accepted to give the best engineering solution.

Power Distribution

Reference should be made to Fig.1 which shows the basic power distribution at a typical UHF main station.

At all sites where the supplies are metered at high voltage, indoor type switchgear is used, and a high voltage switchroom has been established. The HV switchgear comprises oil insulated units which can be isolated and withdrawn for maintenance. (Fig.2.)

The standard fault rating of the 11,000-volt switchgear which has been adopted by all the Electricity Boards relative to their system design is 250 MVA, with a voltage impulse level of 75 kV.

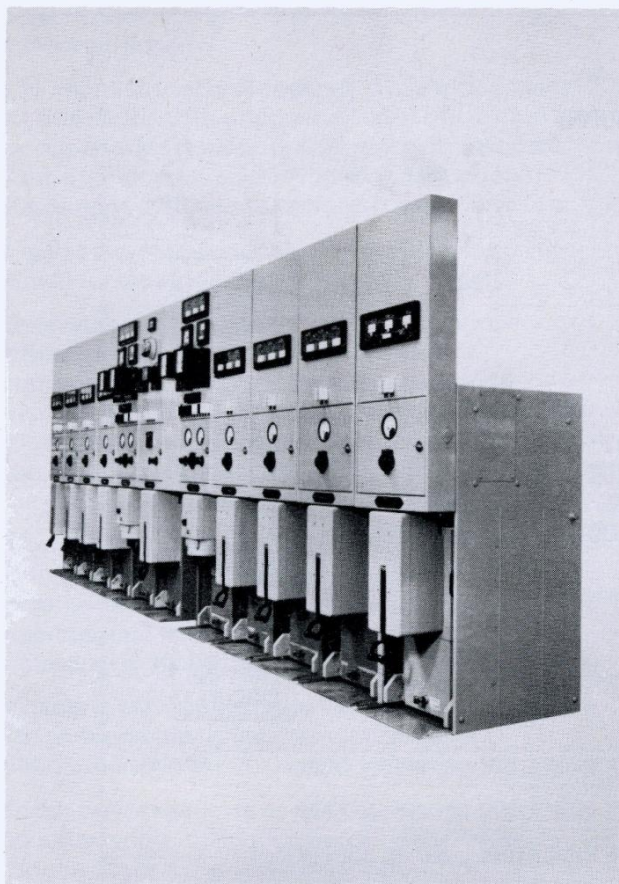


Fig.2. 11,000-volt oil-filled circuit breaker switchgear of the type used at a UHF main transmitting station.

A fixed type CO₂ automatic fire protection installation is provided in each HV switchroom.

The IBA have installed outdoor type power transformers manufactured to the British Electricity Board's specification, and these are located as close as practical to the transmitter load. The transformers are oil immersed, naturally cooled, with primary off-circuit tap-changing facilities to allow $\pm 2\frac{1}{2}\%$ and $\pm 5\%$ variation. The rating of each is sufficient to deal with the anticipated future load, including the fourth UHF programme.

The medium voltage switchboard is located in the transmitter hall. It is of the cubicle type and includes air circuit breakers to control the incoming supplies from the transformers. (Fig.3.)

The bus section air circuit breaker can give complete electrical separation of the 415/240 volts installation

connected to each half of the switchboard. This enables one section to be isolated for maintenance purposes, whilst retaining the essential technical and domestic supplies to keep one complete transmitter in operation. This is in accordance with the policy at main stations of completely duplicating both the transmitter equipment and power supply feeds.

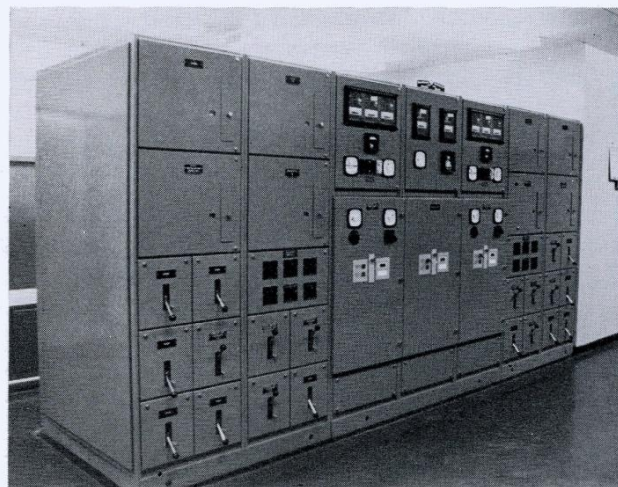


Fig.3. Medium-voltage (415-volt) cubicle-type switchboard as installed in the transmitter halls of UHF main stations.

The cables connecting the transformers have been installed underground and are copper or aluminium conductor, paper insulated, lead covered, steel wire armoured, with an overall PVC sheath.

Multi-core PVC insulated SWA PVC sheathed pilot cables have also been installed between the HV switchroom and the MV switchboard to provide for switchgear intertripping, and remote submetering of the current.

Automatic Changeover of Supplies

Since all UHF stations are designed for unattended operation the changeover of two electricity supplies has to be achieved automatically.

At the majority of stations provided with duplicate supplies, these cannot be operated in parallel, and automatic changeover is provided either at high voltage or medium voltage depending upon the declared point of supply. At a few sites the Electricity Board operates the supplies on a closed ring system with directional protection on the system circuit breakers, so that a faulty section of the ring can be automatically isolated leaving one healthy supply to the site.

The principle used for the automatic operation is the same applied either to the high-voltage

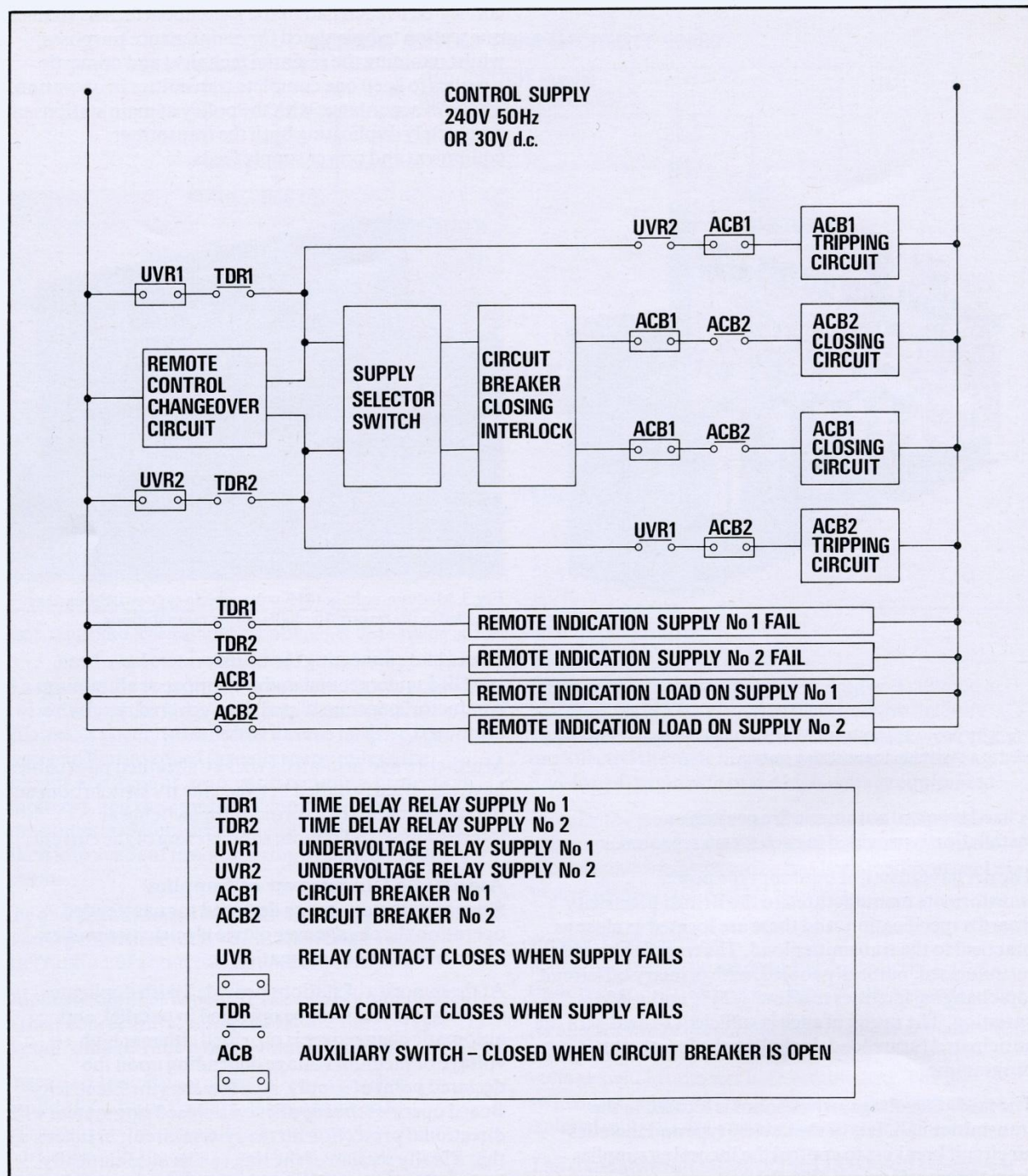


Fig.4. Simplified diagram of the automatic supply changeover system for a main UHF station showing the control circuits for the automatic changeover of two supplies.

oil-circuit-breakers or the medium-voltage air-circuit-breakers.

The ability to trigger the operation of a spring-charged closing mechanism, and a mechanical trip to open the circuit-breaker (by means of 30-volt coils energised from a battery source) is involved in each case. Recharging of the closing springs is motorised.

Fig.4 shows a simplified block diagram of the control circuit for the automatic operation.

Relays monitor the state of the incoming supplies, and a time lag is incorporated to mask transient conditions. The relay arrangements include an adjustable time delay of up to about five seconds before the changeover is initiated to allow for the operation of the Electricity Board's auto reclose circuit breakers that may be involved in the particular network.

The use of auto reclose circuit breakers is quite common with high voltage overhead line supplies, because many faults are of a transient nature, caused by lightning and wind blown debris shorting the uninsulated conductors of the line.

Changeover to the alternative supply is initiated when the preferred supply fails providing that the alternative supply is in a healthy state.

In the event of a changeover taking place to the standby supply, the system will not change back automatically to the preferred supply when it is restored, to prevent an unnecessary interruption to the public transmissions.

Electrical interlocks are provided to ensure that only one feeder circuit breaker can be in the closed position at any time.

By means of auxiliary contacts on the circuit breakers and the control relays, remote indication is given over a 'Teledac' system of the operating conditions of the supplies, and in the case of the medium voltage changeover installations remote control of the changeover is provided over the 'Teledac' system.

Protection of Installations

Effective and rapid isolation of any defective circuit is an essential aspect in the reliability of the power supplies. An important aspect of protection is the consideration of the maximum value and duration of the short circuit current that could occur at any point in the installation, since the protection characteristics must be appropriate to the current time capability of the equipment and wiring which is to be protected.

The current grading of the protection devices in series is essential to give discrimination and to prevent unnecessary and/or unacceptable disconnection of the healthy parts of the system.

The forms of protection used in IBA installations are mainly:

- (a) Induction disc type relays (IDMT) operating from the 5 amp secondaries of current transformers which are used mainly on HV and MV circuit breakers.
- (b) High breaking capacity (HBC) fuses which are used extensively for submain and final circuit protection.
- (c) Miniature circuit breakers (MCB) which are used for final circuit protection.

In practice the operating time of each device in the circuit path can be plotted against the current which may be expected to flow during a short circuit. The prospective value of fault current is governed by the electrical components in the supply network from the source of generation, and a typical value at the 415 volts switchboard of a transmitting station would be a symmetrical current of 14,000 amps.

Earth current leakage indication is provided on all the MV switchboards, and at main stations an earth leakage alarm facility is provided over the 'Teledac' system, which will respond to an earth fault current of approximately 15% of the full load current.

Restricted earth fault protection is applied to the transformers owned by IBA at Phase 1 stations, with intertripping of the HV and MV circuit breakers.

The medium voltage earthing arrangements at all IBA stations provide a metallic earth path back to the neutral point of the transformer star connected secondary winding, and this gives a sufficiently low value of earth loop impedance to satisfy the IEE wiring regulations relating to the use of HBC fuses for protection against earth leakage currents.

Automatic Voltage Regulation

As previously mentioned it is necessary to keep the power supplies to the transmitters within much closer limits of voltage variation than can be expected from the mains supply. The voltage limits specified for the operation of the transmitters is $\pm \frac{1}{2}\%$ of the phase voltage (240 volts), as compared with the statutory voltage limits of $\pm 6\%$ included in the Electricity Supply Regulations 1937.

Automatic voltage regulators have therefore been installed in the feeds to each transmitter. These have a

rating of 150 kVA 3-phase for each 25 kW transmitter, and 85 kVA for each 10 kW transmitter (Fig.5). The regulators have a correction range of $\pm 10\%$.

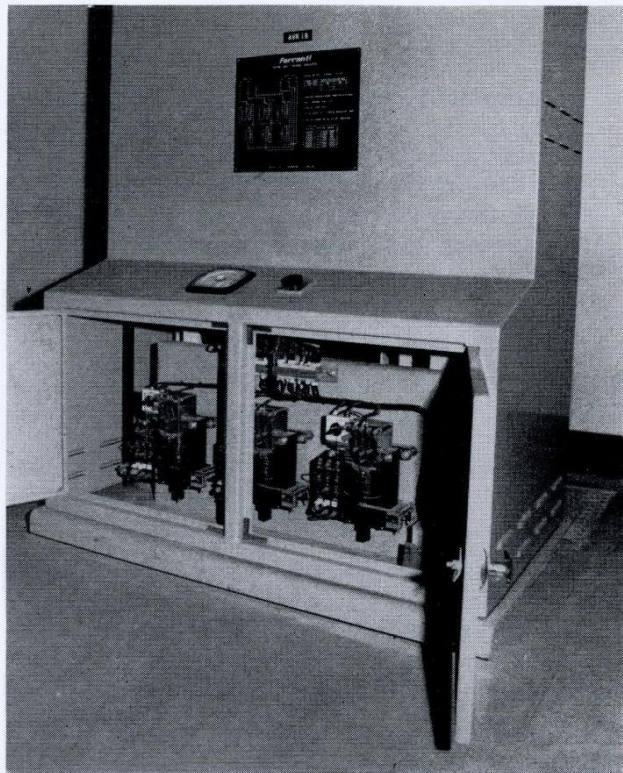


Fig.5. Automatic voltage regulator rated at 85 kVA as installed in the power feed to each 10 kW transmitter at a UHF main station.

The speed of response of the regulators (minimum of 1 volt per second) is not considered to be a prime factor as the voltage regulation is related to the electricity supply network conditions, rather than any load variation of the transmitters. The regulators are therefore of the electro-mechanical type and are naturally air cooled.

In the Phase 1 stations, involving the higher ratings, moving coil regulators have been used which are controlled separately on each of the three phases by a voltage sensitive relay, with mercury switch contacts, in the circuit of an induction disc type motor drive.

The Phase 2 stations have been equipped with regulators which employ a motor-driven variable auto transformer feeding a buck/boost transformer.

The control is achieved on each phase by a transistorised sensor unit and reversing drive system to

move the variable transformer brushgear to give the required voltage output.

Wiring

The complete electrical installation design is in accordance with the Institution of Electrical Engineers wiring regulations, the IBA safety regulations, and the British Standard Codes of Practice. Specialised equipment such as switchboards, control panels, and automatic voltage regulators, are purchased direct from manufacturers as the result of a competitive tendering procedure. The wiring installations are carried out under contracts placed with national electrical contractors, who are issued with detailed specifications and drawings covering the complete work.

In relation to the size of a station building the amount and complexity of the wiring is substantial. In addition to the power wiring to the transmitters and auxiliary equipment, mains wiring is involved for ventilation plant, programme input equipment, aerial feeder control equipment, battery units, and mast aircraft obstruction lighting. The domestic supplies include the provision of lighting, general purpose socket outlets, and a limited amount of space heating. The extra low voltage (ELV) wiring includes audio and video circuits, and remote control and indication wiring connected to the 'Teledac' system.

The wiring is carried out using a metal trunking system with conduit extensions, installed mainly on the surface of the fair faced brickwork. At Phase 1 main stations an under-floor fibre pipe duct system has been used in the transmitter hall associated with the concealment of the wiring installation using a plastered wall finish and a suspended ceiling.

The ELV wiring is installed in a separate trunking and conduit system to segregate it from the mains wiring, and reduce the possibility of electrical interference. Particular attention is given to the earthing system of the installation.

All trunking runs are provided with an earth conductor which is bonded to the trunking at regular intervals. In general each circuit is provided with an earth conductor of at least half the conductance of the largest conductor of the circuit, disregarding the contribution to the earth continuity made by the other earthed metalwork.

The creation of earth loops in the physical routing of circuits is avoided as far as practical, since this can

cause interference to the operation of the transmitter equipment.

The aerial mast or tower has its own earth electrode system to protect against the effects of lightning. This system is bonded to the electrical installation earth electrode system.

The completed electrical installations are inspected and tested by IBA electrical inspectors employed in the regions, in addition to the contractual obligations of the electrical contractor to test the installation in accordance with the IEE wiring regulations.



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